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EXPLANATORY MODELING OF TRANSBAY TRAVEL CHOICE

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BART IMPACT PROGRAM

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OCTOBER 1977

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NOTICE

BART Impact Program
Transportation System and Travel Behavior Project

Explanatory Modeling of Transbay Travel Choice

Prepared by
Peat, Marwick, Mitchell & Co.

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16. Abstract

The 71-mile Bay Area Rapid Transit (BART) System, serving San Francisco, Oakland, Berkeley, and their suburbs, is the first regional-scale rapid transit system to open in the United States in over 50 years. This report is one of a series assessing the impact of BART on transportation and travel in the Bay Area. The report analyzes the reasons underlying BART-bus and BART-automobile travel choices in the key transbay travel corridor linking San Francisco and Oakland.

Travel modes are defined in terms of 14 service attributes including quantifiable attributes such as travel time and cost, and more difficult-to-quantify attributes such as dependability and safety. Disaggregate models which relate mode-choice probability to perceived satisfaction with the alternative modes are estimated using data for the 14 attributes collected by semantic differential scales. Several different models are estimated and compared for BART-bus and BART-auto choices, for work and nonwork trip purposes, for geographic stratifications of the data, and using linear and logit functional forms.

The models provide convincing explanations of mode choice behavior and show that travel time and travel time-related attributes such as dependability and flexibility are the dominant determinants of choice. However, large improvements in BART's service are indicated as necessary to increase ridership significantly assuming bus and automobile service levels remain unchanged.

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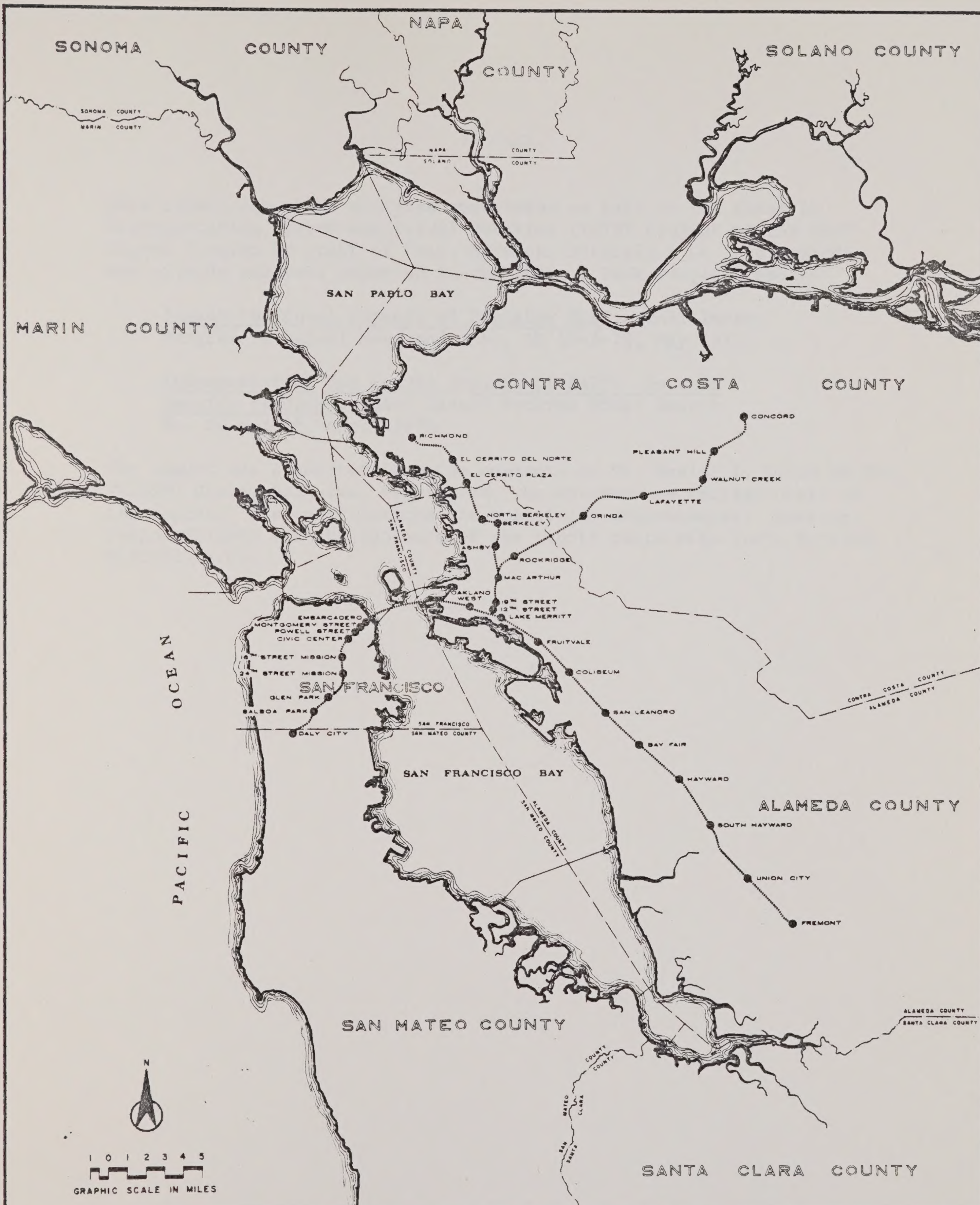

BAY AREA RAPID TRANSIT SYSTEM

PEAT, MARWICK, MITCHELL & CO.
SAN FRANCISCO

PREFACE

This report describes analyses undertaken as part of the Phase II Transportation System and Travel Behavior (TSTB) Project of the BART Impact Program by staff of Peat, Marwick, Mitchell & Co. It updates and extends analyses reported in two Phase I TSTB Project reports:

> Immediate Travel Impacts of Transbay BART. BART Impact Program Technical Memorandum No. TM 15-3-75, May 1975.
>
> Transportation and Travel Impacts of BART: Interim Service Findings. BART Impact Program Final Report No. FR 6-3-75, April 1976.

The report has benefited from the comments of Mr. Daniel I. Riley of The TRANSPO Group, Bellevue, Washington, who reviewed an earlier draft of the report. His contributions are gratefully acknowledged. However, responsibility for the contents of the report rests with Peat, Marwick, Mitchell & Co.

SUMMARY AND CONCLUSIONS

Study Objectives and Scope

BART, the 71-mile, 34-station Bay Area Rapid Transit System, was opened in stages from September 1972 to September 1974, the last stage being the underwater transbay tube linking the downtowns of San Francisco and Oakland. The transbay tube also parallels the heavily traveled San Francisco-Oakland Bay Bridge. In October 1974, about six weeks after the start of transbay BART service, the BART Impact Program conducted a series of on-route surveys of transbay travel by BART, bus, and automobile. About 2,000 people traveling by each mode were surveyed. The overall purpose of this report is to present the results of analyses of the data from these surveys. The specific objectives are twofold:

- Estimate and evaluate alternative mathematical models to explain travelers' mode choices in terms of a comprehensive set of modal service attributes.

- Analyze the reasons underlying travelers' BART-bus and BART-automobile choices, and assess the relative importance of different service attributes in these choices.

Strictly, the analyses apply only to transbay travel at a time soon after the start of service, and are not necessarily valid for travel on other parts of the system or for later periods. However, neither transbay BART service nor ridership has changed radically since October 1974. Transbay ridership has increased from about 52,000 trips per day at the time of the survey to about 61,000 currently (July 1977). Therefore, the results can probably still be considered to apply, at least for transbay travel.

The modal choice decisions of two groups of travelers are analyzed: those choosing between BART and automobile and those choosing between BART and bus. For each of the BART-auto and BART-bus choice groups, travelers are divided according to their trip purpose: (1) trips to and from work, and (2) nonwork trips. Travelers making work trips are further stratified according to the "access" mode that is (or would be) used by the traveler to get to the BART station (bus, automobile, or walking); and according to the BART station that is (or would be) used. Seven groups of East Bay BART stations are analyzed. Thus, separate modal choice relationships are developed for 24 different traveler groups. In addition, different mathematical model forms are estimated and evaluated for each group.

The mathematical models attempt to explain the modal choices of travelers in terms of 14 "attributes" describing the service provided

by BART and the alternative modes. Some of these attributes, such as travel time and cost, may be quantified rather easily; others, such as comfort and dependability, are more difficult to quantify. The attributes and the abbreviated terms used for them are:

Attribute	Abbreviation
• Total door-to-door travel time	Total time
• Walking time during the trip	Walking time
• Time spent waiting	Waiting time
• Dependability of arriving on time	Dependability
• Chance of getting a seat	Chance of seat
• Comfort and smoothness of ride	Comfort
• Safety from accident or injury	Safety
• Security from crime and unpleasant behavior of other people	Security
• Feeling of privacy	Privacy
• Ability to do what you want while traveling	Activity en route
• Flexibility to travel when you want	Flexibility
• Ability to combine different purposes in a single trip	Multipurpose
• Total cost of door-to-door trip	Total cost
• Ability to find a place to park	Parking space

As mentioned, one of the basic objective of the study is to estimate the relative importance of these attributes in travel modal choice. The mode choice models are "explanatory" in that they attempt to explain and enhance understanding of why travelers choose between BART and either bus or automobile. The models are not primarily intended for predicting BART ridership as a function of assumed BART service characteristics. Nevertheless, the report does attempt to make use of the mode choice models to indicate the likely sensitivity of BART ridership to assumed changes in its service attributes. Given the shortcomings of the models as predictive tools, these ridership sensitivity analyses need to be interpreted cautiously.

Mode Choice Models

The mode choice models developed in the study relate the probability of an individual traveler choosing between BART and automobile or BART and bus to explanatory variables describing differences in the levels of the attributes for the alternative modes. The explanatory variables are ratings of satisfaction with the attributes as measured on 7-point semantic differential rating scales. (These ratings were sought in the survey for all 14 attributes for both BART and the alternative modes).

Two mathematical models are investigated: the linear probability model and the nonlinear binary logit model. Both models estimate the constant term and coefficients of a linear function of the explanatory variables. The results of these two models are compared. In addition, variations of the two basic models are investigated. In one, the dependent variable is specified as a continuous probability variable (which can take on any value between zero and one); in the other, it is specified as a dichotomous (zero-or-one) variable.

The value of attribute i for mode j is designated as X_{ij}. For example, this might be the value of the "total travel time" attribute, measured in minutes, for the BART mode. Associated with X_{ij} is an attribute satisfaction rating designated as Q_{ij}. This is the semantic differential scale rating, measured on a scale of 1 to 7 for attribute i for mode j (in the case of the example, the travelers' satisfaction with BART's total travel time.) The X_{ij} are referred to as <u>attribute values</u> and the Q_{ij} are referred to as <u>attribute satisfaction ratings</u>. The mode choice models express the probability of choosing BART (say mode j) over the alternative mode (say mode k) as a function of differences between the attribute satisfaction ratings (Q_{ij} minus Q_{ik}) for all attributes i = 1 to m. The differences ΔQ_i are referred to as the <u>relative attribute satisfaction ratings</u>.

If a linear function $g(\Delta Q_i)$ is defined as

$$g(\Delta Q_i) = a_o + \sum_{i=1}^{m} a_i \, \Delta Q_i$$

where a_o and a_i are constants, and the probability of choosing BART over the alternative is designated y, then the linear model is given by

$$y = g\,(\Delta Q_i)$$

and the logit model is given by

$$y = 1/(1+e^{-g(\Delta Q_i)})$$

The coefficients a_i (as estimated by ordinary least-squares regression in the case of the linear model and by an iterative maximum-likelihood procedure in the case of the logit model) give estimates of the relative importance of the various attributes. Specifically, the ratio of the coefficients a_i/a_k gives the importance of attribute i relative to attribute k in the mode choice decision.

Limitations of the Models

The models adopted in the study embody assumptions about peoples' travel behavior that are open to challenge. In particular (and in common with most similar "disutility" mode choice models), the models assume that an individual's satisfaction with one attribute value (for a given mode j) does not depend on the values of the other attributes (for the same mode j). Stated mathematically, Q_{ij} is assumed to be independent of X_{kj} for all $k \neq i$. This may not always hold. For example, a traveler's satisfaction with a given level of comfort is likely to be higher for a short trip than for a long trip. In this study an attempt was made to reduce possible errors introduced by this assumption by stratifying the sample by origin stations, thereby grouping together individuals with similar travel times.

The limitations of the data set from which the model coefficients are estimated clearly also have implications for the meaning of the results. Two of these limitations should be mentioned here. As with any statistical-inferential model, the procedures used to estimate the coefficients of the mode choice models depend on variation within the observed data. If little or no variation exists among the observations of individuals' satisfaction ratings for a particular attribute--if for example, nearly all travelers rate their satisfaction with the safety of both BART and bus very highly--then this attribute will not be indicated by the model as a significant factor in their choice. This will be the case even though safety may well be very important to them in an absolute sense or where a choice is made between two modes, one of which is perceived as safe and one as unsafe. The estimates of relative importance produced by the models apply only to the specific choice being considered: Given, say, a choice between BART and bus where both modes are perceived as safe, safety is indeed not important in that choice. The fact that the model results depend on the peculiarities of the data for the observed choice emphasizes the dangers of using these explanatory models in prediction. Caution must be exercised in attempting to use the models to predict choices where the alternative modes take on attribute values much different from those used in estimating the models.

A second potential problem with the use of satisfaction ratings data observed for a large number of attributes--all of which the respondent is required to rate--is that an irrelevant attribute may be inferred by the model to be important simply because of (perhaps fortuitous)

correlation with the dependent variable. The only defense against this problem is to include in the analysis only those attributes which are, by prior assumption, relevant to the mode choice.

Correlations Among Mode Choice Factors

As is to be expected where semantic differential ratings are collected for as many as 14 different modal attributes, there exist many high intercorrelations between the relative satisfaction ratings. These arise for two related reasons: (1) the words used to describe two different attributes may mean essentially the same thing to many people as in the case of "privacy" and "security from crime and unpleasant behavior of other people" and (2) different attributes are related by functional "supply" relationships, for example, "time spent waiting" and "dependability of arriving on time." A principal components (factor) analysis of correlations among the data confirms that people think in terms of fewer than 14 separate mode choice decision factors; nine components are indicated by the analysis as accounting for nearly all the within-sample variance. Particularly noteworthy is the very high correlation between the relative satisfaction ratings for the attributes of total door-to-door travel time and dependability. All three of these attributes are intuitively important in travel mode choice, perhaps particularly (in the case of dependability) where BART is concerned; and all three appear to be very closely identified with one another by people in making their mode choice decisions. In fact, it is not possible in this study to distinguish the three as separate variables to explain mode choice. To reduce the problems of multicollinearity in the explanatory mode choice models, not all 14 variables were used in estimating the mode choice model coefficients. Instead, a subset of nine (representing the nine principal components) was used. Thus, five attributes are included in the analysis of relative attribute importance "by proxy." The dependability attribute, for example, is represented by the total travel time attribute. Thus, where total travel time is indicated as an important attribute, the importance of dependability is also implied.

Methodological Conclusions

The results of the principal components analysis are intuitively satisfactory and generally provide confidence that attribute satisfaction data observed by semantic differential rating scales form a reasonable basis for explaining modal choice in terms of all attributes, both those that are easily quantified and those that are not so easily quantified. This is confirmed by the model estimations themselves, which in general show intuitively reasonable and internally consistent results. "Goodness-of-fit" measures calculated for the models are typically fairly low, but in all cases highly significant, statistically speaking.

Comparison of the estimates of attribute importance as inferred from the models and corresponding estimates of attribute importance as reported directly in the survey questionnaire also tends to support the model results. The inferred and reported importance ratings are broadly similar although a number of differences do exist with regard to individual attributes. These differences in part reflect the point made earlier: that the estimates of attribute importance estimates produced by the models apply to the specific choice situation observed, while the importance ratings reported by respondents directly in the questionnaire may apply to a rather different (although undefined) choice situation. However, the general similarity between the inferred and reported ratings of attribute importance does suggest that, for many applications, importance ratings collected directly from questionnaire responses may be adequate, and more sophisticated and expensive statistical inference models may not be justified.

The linear mode choice model estimated by least-squares regression and the nonlinear logit model estimated by the maximum-likelihood procedure consistently give very similar results. The reason presumably is that the data used to estimate the models are distributed along a portion of the logistic function that is closely approximated by a linear function. If this finding is generally true in mode choice analyses, then it suggests that, in many applications, simple linear regression model formulations may be perfectly adequate, even though they are not as sound structurally (or "behaviorally") as more complex nonlinear models.

Comparison of the choice models incorporating a binary (zero or one) dependent variable with corresponding models formulated with a continuous probability (between zero and one) dependent variable also shows the simpler binary variable to provide results that are as good as (or better than) results obtained with the more sophisticated dependent variable formulation.

A number of alternative functional forms were tested for the relationship between the perceived attribute satisfaction rating for a given attribute value (Q_{ij}) and the attribute value itself (X_{ij}). These are referred to as Q/X relationships. Linear, negative exponential, and sigmoid-curve functional forms were fitted to the data for selected attributes. Here, too, the nonlinear (exponential and sigmoid) relationships, although theoretically preferable, do not provide demonstrably better fits to the data than the simple linear model.

Important Factors in Mode Choice

Reflecting the different choice situations faced by different traveler groups, the results of the model estimations show significant differences among the various sample stratifications, particularly in comparisons of (1) travelers making BART-automobile choices and those making BART-bus choices and (2) travelers making work trip choices and those making

nonwork trip choices. This is illustrated by the following tabulation, which shows all attributes appearing as statistically significant in the models, listed in the order of their inferred importance. (The smaller number of attributes appearing for nonwork trip choices reflects the relatively small samples of data available for estimation.)

MODAL ATTRIBUTES CONSIDERED IMPORTANT IN THE CHOICE DECISION

BART-Automobile Choices		BART-Bus Choices	
Work Trips	Nonwork Trips	Work Trips	Nonwork Trips
Flexibility	Total time	Total time	Safety
Total time	Multipurpose	Walking time	Total time
Security	Parking space	Total cost	
Walking time		Safety	
Total cost		Activity en route	
Activity en route		Security	
		Parking space	
		Flexibility	

For all groups shown, total travel time appears as one of the top two most important attributes. As mentioned, this implies that the dependability attribute is also an important factor in travel mode choices. The time spent walking is also explicitly an important determinant of mode choice for work trip-makers.

In addition to the travel time-related attributes, for people choosing between BART and automobile for the work trip, the attributes of flexibility to travel when you want and security are indicated as important. Not surprisingly, for both of these attributes, the automobile is perceived more favorably than BART. For nonwork BART-automobile choices, the ability to combine different purposes in a single trip and the ability to find a place to park are important, the latter reflecting the difficulties of finding parking space at BART stations during the day.

For people making BART-bus choices for their work trips, in addition to the travel time/dependability and walking time attributes, the cost and safety attributes are indicated as important.

Sensitivity of BART Ridership to Attribute Changes

The study clearly indicates that the choice between BART and automobile or bus is principally determined by relative travel times and the relative values of other time-related attributes. This implies that BART's ridership is most likely to be increased by improvements in BART

reliability and reductions in the expected time spent in walking, waiting, and traveling on the System. In spite of the (already mentioned) dangers involved in applying the explanatory models developed in this study to prediction, an attempt is made to quantify the changes in BART ridership that might be expected to result from hypothesized changes in specific BART attributes by applying the mode choice models. The specific attributes investigated are those over which BART management can exercise some influence: total door-to-door travel time, walking time, total travel cost, and chance of seat.

The analysis of BART ridership sensitivity confirms the conclusions of the explanatory analysis of relative attribute importance: Reductions in the total time spent traveling on BART have by far the greatest potential for increasing BART ridership. Assuming that the service characteristics of the bus and automobile modes remain unchanged, a 25% average decrease in the total door-to-door travel time for transbay BART trips (equivalent to an average 15-minute travel time reduction) would increase transbay BART work trip travelers by an estimated 8% or about 2,200 transbay riders daily. In contrast, a 25% reduction in total BART travel cost (equivalent to an average fare reduction of about $0.40) is indicated by the model to increase ridership by only about 1%.

However, these ridership sensitivity results, which suggest that very large (and possibly infeasible) improvements in BART travel times would be required to increase BART ridership appreciably, cannot be considered conclusive. Because of high correlations among the explanatory variables, it is likely that the ridership sensitivity estimates produced by the attribute satisfaction-based models understate the change in ridership which would result from improvements in BART travel times. Uncertainties about the results of the attribute satisfaction-based models are emphasized by the results of mode choice models estimated directly from reported values of the time and cost attributes. The latter suggest that a 25% average decrease in total door-to-door BART travel time would increase BART ridership by an estimated 25%.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. MODEL SPECIFICATION

Modeling Objectives

The "cost" to an individual of making a trip by a transportation mode is a multidimensional quantity describing the levels of monetary cost, time, comfort, convenience, and other perceived modal characteristics. We term these characteristics the attributes of the mode.

Some of the attributes characterizing a mode are defined as "quantitative" because they are generally straightforward to define and measure. Examples are cost, time, and frequency of service. Other attributes such as comfort, safety, privacy, and reliability, which are difficult to define or measure, are termed "qualitative" attributes.

Past attempts to model modal choice have, with few exceptions, relied entirely on quantitative attributes to describe competing modes. It seems clear, however, that many qualitative attributes are highly significant in determining travel decisions, so omitting them completely could seriously weaken the structure of a model that attempts to explain modal choice. In this study, we try to formulate and estimate models which include all the relevant attributes, both quantitative and qualitative.

As with most disaggregate "explanatory" models of travel mode choice, the models formulated here are based on the hypothesis that the behavior of an individual choosing between two modal alternatives is a function of (1) his satisfaction with the attributes of the modes (one mode expressed relative to the alternative mode), and (2) the importance he attaches to the attributes (each attribute expressed relative to the other attributes).

Our models attempt to estimate the relative importance of model attributes, taking as input measurements of individuals' satisfaction with various attributes of two modes. (What is meant by the relative importance of the attributes is defined later in this chapter.) The measurements of attribute satisfaction are obtained from semantic differential scale ratings, as discussed below.

The models estimated in this report are "explanatory", since they attempt to explain and enhance understanding of why selected travel groups choose BART or an alternative mode. The models are not primarily intended for predicting BART ridership or changes in ridership. Among other limitations, the models confine themselves to estimating the modal choice of individuals who actually do have a choice of alternatives, (i.e., are not "captives" of any one mode). The models also consider modal choice as a simple binary decision between the "best" alternatives available. (These assumptions will be discussed further in Chapter II, which deals with the data base and the editing of data.) However, the

models are used in Chapter XIII of the report in an attempt to assess the likely sensitivity of transbay BART ridership to changes in the values of BART's attributes.

The Semantic Differential

The semantic differential is a scaling technique originally developed to measure the intensity and quality of people's attitudes towards abstract concepts on the basis of questionnaire responses. The original technique has been extensively modified and applied in many areas, notably in psychological and marketing research, and recently, travel demand estimation.

For the concept to be measured, the respondent is presented with a scale defined at its end-points by "polar adjectives," which are extreme antonyms, and divided into a number of assumed equal intervals. Each item on the questionnaire might have the following form:

polar adjective X - - - - - - - polar adjective Y
1 2 3 4 5 6 7

where the scale intervals are defined as

1. Extremely X
2. Quite X
3. Slightly X
4. Neither X nor Y
5. Slightly Y
6. Quite Y
7. Extremely Y

and the respondent is required to check one.

Theoretically, any number of intervals can be used, but the 7-point scale is most common. The concepts that can be scaled are unlimited. For example, corporate or specific product "images" are concepts which might interest market researchers. In modal choice research, the pertinent concepts are the attributes of transportation modes such as comfort, safety, dependability, and travel time; and the polar adjectives are such descriptors as acceptable/unacceptable, good/bad, very satisfied/very dissatisfied, or important/unimportant. In this study, semantic differential ratings are used to compare travelers' satisfaction with modal attributes for different modes.

The most convenient method of summarizing the information given by the semantic differential scale is to assign numerical weights to responses in each interval; a linear mapping into a 1 through 7 or -3 through +3

integer scale is the most straightforward for a 7-point scale. Assuming that the measurements produced are interval scaled,* group means and dispersion statistics can be computed and ratings compared between scales. Although the semantic differential provides no test for the assumption of an underlying interval scale, widespread use by marketing researchers has indicated that the procedure does provide a reliable method for developing consumer attitudes on a variety of subjects. The results presented later in this report also provide support for the assumption of interval scaling.

A number of other problems arise in using semantic differential scaled data; among these are variations in respondent interpretation of questions, biases resulting from the sequence in which questions are asked, associative and "halo" effects, and the difficulty of eliciting respondents' true feelings. Some of these problems are discussed later.

Proposed Mode Choice Models

Suppose that a population of travelers can be identified so that an individual traveler is considered representative of the whole population. The term "population" is used here to mean any group of travelers who share certain characteristics with respect to their socioeconomic status or the trip being considered; thus, trip purpose, available modes, or income might all be criteria for defining a population.

Assume further that a typical individual from the population, having decided to make a specific origin-destination trip, has a choice of two available travel modes. Each mode is assumed to be completely identified in terms of m modal attributes, and the choice between modes 1 and 2 is assumed to be made by the individual based on the relative values of the m modal attributes for the trip. In the report, we identify an entire door-to-door journey by the name of the mode used for the major part of the journey. For example, a bus trip includes walking to the bus stop and walking to the destination besides actually riding the bus. Correspondingly, "modal attributes" are the attributes of the complete journey.

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*An interval scale is one which is unique only up to a positive linear transformation (i.e., a transformation of the form $x_1 = a + bx_2$; $a \neq 0$, $b > 0$) in contrast to a ratio scale which is unique up to a positive proportionate transformation (i.e., a transformation of the form $x_1 = cx_2$; $c > 0$). Only differences between interval scale values can be expressed in multiples of one another; the values themselves cannot. Both differences between values and the values themselves can be expressed as multiples of one another for ratio scaled values. Measurements need only be interval scaled for the computation of the standard statistics such as mean, variance, and the product-moment correlations.

The mode's attributes can be quantitative, such as time and cost whose values are directly measurable; or, they can be qualitative, such as comfort and dependability whose values are not easily defined or directly measurable. Using appropriate semantic differential scales, it is generally possible to measure the satisfaction of an individual with both quantitative and qualitative values for a given mode. These are referred to as attribute satisfaction ratings.

Now, define

y = probability that mode 1 is chosen over mode 2

X_{ij} = value or level of attribute i for mode j

Q_{ij} = $Q_i(X_{ij})$ = attribute satisfaction rating associated with attribute value X_{ij}

$U_i(X_{ij})$ = utility associated with attribute value X_{ij}.

Assume that the total utility of a mode to an individual traveler is derived from the sum of the utilities of the mode's attributes, and that the probability of an individual traveler choosing mode 1 is a function f of the difference he perceives in the total utilities of the two modes. Then

$$y = f\left(\sum_{i=1}^{m} [U_i(X_{i1}) - U_i(X_{i2})]\right) \tag{1}$$

The assumption of "additive utilities" is an important one in the model formulation because it implies that the utility associated with one attribute i for mode j, $U(X_{ij})$, is independent of the values of all other attributes $X_{kj} (k \neq i)$ for the same mode j. The validity of this assumption will be considered further in the correlation analysis of the data presented in Chapter III.

The function $U_i(X_{ij})$ is assumed only to depend on the attribute i, i.e., the utility derived from a certain value of some attribute i is the same whether travel is by mode 1 or by mode 2. Furthermore, this function is assumed to be monotonic in X_{ij}. The value M_i is assumed to be the maximum level of utility associated by the traveler with any value or level of the attribute. In general, the value of M_i will be different for different attributes i.

Let the attribute satisfaction rating $Q_i(X_{ij})$ be measured on a semantic differential scale with (k + 1) intervals 0, 1, ..., k, and assume a direct proportionality relationship between $Q_i(X_{ij})$ and $U_i(X_{ij})$.

That is,

$$Q_i(X_{ij})/k = U_i(X_{ij})/M_i \tag{2}$$

Then, combining equations (1) and (2) gives

$$y = f(\frac{1}{k} \sum_{i=1}^{m} M_i[Q_i(X_{i1}) - Q_i(X_{i2})]) \tag{3}$$

Denote $\Delta Q_i = Q_i(X_{i1}) - Q_i(X_{i2})$ as the relative attribute satisfaction ratings for attribute i, then equation (3) can be rewritten as

$$y = f(\frac{1}{k} \sum_{i=1}^{m} M_i \Delta Q_i) \tag{4}$$

Given observations on modal choices and relative attribute satisfaction ratings for a sample of travelers choosing between a specific modal pair, the problem is one of statistically estimating the relationship between the explanatory variables ΔQ_i and the dependent variable y as given by equation (4).

A number of alternative forms may be proposed for the function f. In this study, two forms were chosen:

$$y = g(\Delta Q_i) \tag{5}$$

and

$$y = 1/(1+e^{-g(\Delta Q_i)}) \tag{6}$$

where

$$g(\Delta Q_i) = a_o + \sum_{i=1}^{m} a_i \Delta Q_i \tag{7}$$

in both equations (5) and (6), and

$$a_i = aM_i \tag{8}$$

Equation (5) is the linear probability model, where the parameters a_o and a_i can be estimated using ordinary least-square methods. The model usually presents the problem of heteroskedasticity (unequal variances) due to the dichotomous dependent variable and may also produce some predicted values of y to fall outside the (0,1) interval, which is

inconsistent with the definition of y as a probability. However, while results are not the best in terms of the classical regression model, they are still useful. The linear model is also computationally efficient and has intuitive appeal.

The model given by equation (6) is commonly known as the binary logit model and fits a "sigmoid" curve to a linear function of the data. This model has the advantage of confining the predicted values of the dependent variable to the unit interval. The usual estimation technique is to derive maximum likelihood estimates of the parameters through an iterative procedure.

It has been shown that for choice-based samples (i.e., samples that are based on the outcome of a behavioral choice process), standard maximum likelihood estimation procedures do not produce statistically consistent parameter estimates. This is because the procedures do not strictly maximize the likelihood function.* However, as long as constant terms are specified for each alternative mode except one, the inconsistency is confined to estimates of these constant terms (or the single constant term in the binary choice situation).**

Interpretation of the Estimated Model Parameters

Both the linear model and the logit model yield estimates of the constant term a_o and the coefficients a_i of the linear function

$$g(\Delta Q_i) = a_o + \sum_{i=1}^{m} a_i \Delta Q_i$$

From equation (8), $a_i = aM_i$ $i = 1, 2, ..., m$, so dividing any one of the estimated coefficients a_i by another of the estimated coefficients, say a_k, gives an estimate of $a_i/a_k = M_i/M_k$.

Recall that M_i is defined as the maximum utility which can be derived by an individual from attribute i. M_i/M_k is then the maximum utility which can be derived from attribute i relative to that maximum derived from attribute k. In this sense, we define the ratio of M_i/M_k (or equivalently, the ratio of coefficients a_i/a_k) $i = 1, ..., m$, to be the relative importance of the modal attribute i in the travelers' mode choice decision.

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*Charles F. Manski and Steven R. Lerman. "Alternative Sampling Procedures for Calibrating Disaggregate Choice Models," Transportation Research Record 592, 1976.

**D. McFadden. "Conditional Logit Analysis of Qualitative Choice Behavior," in Frontiers of Economics (P. Zarembka, ed.). Academic Press, 1973, pp. 105-142.

II. THE DATA BASE

The data used in this study consist of the responses of individual travelers to questionnaires handed them during a survey of their trips across the San Francisco Bay in October 1974. A detailed description of the questionnaire and methodology of the October 1974 transbay survey (hereafter simply called the survey) is given in another report.* Each completed questionnaire contains:

1. The actual mode used for the trip.

2. The number of times in the last four weeks that each mode was used for this type of trip.

3. Trip Purpose and origin-destination information.

4. Semantic-scaled attribute satisfaction ratings for 14 modal attributes (Table 1) for both an actual (or hypothetical) BART trip and an alternative mode (either bus or automobile).

5. The four most important attributes in choosing the mode used.

6. Attribute value information for some quantitative (time and cost) attributes measured for both BART and the alternative mode.

7. Socioeconomic and demographic information about the traveler, including car ownership and availability.

A total of 6,000 returned questionnaires form the main data base of the survey covering automobile users, bus users, and BART users (approximately 2,000 responses for each group). From this data base, two basic files were derived: the BART versus Automobile File and the BART versus Bus File. Screening and editing of the data are described below.

It should be noted that the data apply only to transbay travel. Transbay trips are generally longer than trips made in other parts of the region and differ in other respects, too. Therefore, caution must be exercised in generalizing results to other (non-transbay) travel situations. Also, the survey was conducted very soon (about six weeks) after the start of transbay BART service. Perceptions and attitudes may have changed since then.

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*Surveys of Transbay Travel, October 1974: Data Collection Methodology. BART Impact Program Document No. DD 4-3-75. Prepared by Peat, Marwick, Mitchell & Co., for the Metropolitan Transportation Commission, May 1975.

Table 1

MODAL ATTRIBUTES INCLUDED IN SURVEY QUESTIONNAIRE

Attribute Number	Description	Abbreviation
1	Total door-to-door travel time	Total time
2	Walking time during the trip	Walking time
3	Time spent waiting	Waiting time
4	Dependability of arriving on time	Dependability
5	Chance of getting a seat	Chance of seat
6	Comfort and smoothness of ride	Comfort
7	Safety from accident or injury	Safety
8	Security from crime and unpleasant behavior of other people	Security
9	Feeling of privacy	Privacy
10	Ability to do what you want while traveling	Activity en route
11	Flexibility to travel when you want	Flexibility
12	Ability to combine different purposes in a single trip	Multipurpose
13	Total cost of door-to-door trip	Total cost
14	Ability to find a place to park	Parking space

Screening the Data

The BART versus Automobile File. This file contains responses from both (1) present automobile users and (2) BART users who previously used the automobile mode. Excluded from the file are people who effectively do not have a choice between the two modes. This is achieved by eliminating BART users who are on a BART excursion/touring trip, automobile users who are using a company car, automobile users who have not tried BART, and individuals who do not make the same trip in the opposite direction by the same mode. Individuals who rate the automobile at least as satisfactory as BART for all 14 modal attributes but actually use BART or vice versa are also excluded. Responses were further checked for consistency and excluded for various reasons, such as individuals reporting extremely small or large trip times and trip costs (total door-to-door travel times less than 10 minutes or greater than 3 hours and BART users reporting trip costs less than the minimum fare), and automobile drivers without a driver's license. Excluding all these people yields the BART-auto choice sample of 861 individuals used in the modeling analyses reported here.

The BART versus Bus File. This file contains responses from (1) present bus users and (2) BART users who previously used bus for transbay travel. The screening criteria are much the same as those used for screening the BART versus Automobile File, the intent being to devise a sample of travelers who do have a choice between the two modes. Most of those excluded are individuals who have not tried BART, who are on a BART touring trip, who do not make the same trip in the opposite direction by the same mode, or who reported that they used a bus line for the transbay trip that is not in the set of transbay bus lines. A BART-bus choice sample of 1,623 individuals remains after screening out these respondents.

Editing the Data

Editing the data is mainly a task of filling in missing values for individual responses. Because the questionnaire included so many questions, many respondents, purposely or otherwise, left one or more questions unanswered. Excluding all observations with one or more missing values would greatly reduce the sample available for use in the modeling analyses.

Therefore, values are assigned for missing data in two steps. First, if a response is obvious, an appropriate value is assigned. For example, if the satisfaction rating for the attribute "chance of getting a seat" is missing for the automobile mode, a rating of 7 is automatically assigned. Second, a sample distribution for each satisfaction variable is obtained, and each response that contains missing data for that variable is randomly assigned a value so that the sample distribution

remains approximately unchanged. For example, suppose that the satisfaction rating for a particular attribute is missing for 20 of the respondents. If the sample distribution (not counting the incomplete responses) is 21%, 25%, 35%, and 19% with satisfaction ratings of "3," "4," "5," and "6," respectively, then the 20 respondents with missing values are assigned satisfaction ratings so that 4, 5, 7 and 4 respondents will have ratings of "3," "4," "5," and "6," respectively.

Selection of Samples for Analysis

For comparing travelers' modal choices, the analysis uses selected samples from the (screened and edited) BART versus Automobile and BART versus Bus Files. Many stratifications are possible. The difficulty is in selecting samples that are both of adequate size and form reasonably homogeneous groups. The following stratifications are used in the study:

- Trip Purpose stratification is considered in Chapters IV and V of this report. Individuals are grouped for two types of trips: work and nonwork. The latter consists of many different types of trips such as personal, shopping, educational trips, etc. Grouping these trips was was necessary owing to sample size limitations.

- Origin BART station stratification groups individuals by the origin BART station they actually use or would use (Chapters VIII and IX).

- Access mode to BART station is a stratification that groups individuals by the access mode they actually use or they would use if they were to make the trip by BART (Chapters X and XI).

The last two stratifications are only applied to the work trip sample, because the nonwork trip sample is too small. A summary of the sample stratifications and their sizes is presented in Table 2. In the following chapter, correlations among the relative attribute satisfaction ratings are analyzed to understand the structure of the data.

Table 2

SAMPLE STRATIFICATION
FOR BART VERSUS AUTO AND BART VERSUS BUS

Sample Number	Sample Size	Mode Choice	Trip Purpose	Access Mode	BART Station/Corridor
1	718	BART/Auto	Work	All	All
2	59	BART/Auto	Work	Bus	All
3	127	BART/Auto	Work	Walk	All
4	532	BART/Auto	Work	Auto	All
5	114	BART/Auto	Work	All	Oakland Stations
6	71	BART/Auto	Work	All	Southern Richmond Line Stations
7	123	BART/Auto	Work	All	Western Concord Line Stations
8	83	BART/Auto	Work	All	Northern Fremont Line Stations
9	38	BART/Auto	Work	All	Northern Richmond Line Stations
10	210	BART/Auto	Work	All	Eastern Concord Line Stations
11	79	BART/Auto	Work	All	Southern Fremont Line Stations
12	143	BART/Auto	Nonwork	All	All
13	1,518	BART/Bus	Work	All	All
14	281	BART/Bus	Work	Bus	All
15	253	BART/Bus	Work	Walk	All
16	984	BART/Bus	Work	Auto	All
17	158	BART/Bus	Work	All	Oakland Stations
18	157	BART/Bus	Work	All	Southern Richmond Line Stations
19	137	BART/Bus	Work	All	Western Concord Line Stations
20	193	BART/Bus	Work	All	Northern Fremont Line Stations
21	115	BART/Bus	Work	All	Northern Richmond Line Stations
22	643	BART/Bus	Work	All	Eastern Concord Line Stations
23	115	BART/Bus	Work	All	Southern Fremont Line Stations
24	105	BART/Bus	Nonwork	All	All

III. ANALYSIS OF CORRELATIONS AMONG THE DATA

This chapter is concerned with samples 1, 12, 13, and 24 as defined in Table 2. They are, respectively, work and nonwork samples with BART-auto choice, and work and nonwork samples with BART-bus choice. Analysis of the other samples yields similar results.

Tables 3 through 6 show the simple correlation matrices among the differences in attribute satisfaction ratings (BART minus auto or BART minus bus) for the four samples. As shown, the correlations between the relative attribute satisfaction ratings are high for many attributes, which is to be expected given the large number of attributes used to describe the modes.

An equal-tails test of the null hypothesis that the true population correlation coefficient for any pair of variables is zero gives critical points of 0.076 at the 5% significance level and 0.099 at the 1% level for the BART-auto work trip choice sample (Table 3). This is to say, if the population correlation coefficient between a pair of variables in this sample in in fact zero, a sample correlation coefficient of greater than 0.099 will occur with a probability of less than 0.01 in repeated experiments with the same sample size. The correlation matrix of Table 3 shows that of the 91 elements to one side of the principal diagonal, 82 are greater than 0.099. This demonstrates that statistically speaking, many highly significant correlations exist.

For the BART-auto nonwork trip choice sample, the corresponding critical values are 0.164 and 0.215 at the 5% and 1% significance levels, respectively. Of the 91 off-diagonal elements of the correlation matrix given in Table 4, 48 are significantly different from zero at the 1% level. Similarly high correlations are shown for the BART-bus choice samples in Tables 5 and 6.

These generally high correlations may be partly attributable to the so-called "halo" effect which frequently arises in questionnaire responses as a result of a dominant overall impression tending to influence individuals' responses to all questions in a similar way. For example, a respondent may tend to give high satisfaction ratings to all attributes of a mode because he is highly satisfied with one very important attribute.

The high correlations give rise to the problem of multicollinearity if we attempt to include correlated attributes as explanatory variables in a multiple regression model. The problem arises in interpreting the estimated coefficients because it becomes very difficult, if not impossible, to distinguish between the separate influences of the explanatory variables and obtain a reasonably accurate estimate of their relative effects.

Table 3

MATRIX OF SIMPLE CORRELATION COEFFICIENTS FOR RELATIVE
(BART MINUS AUTO) ATTRIBUTE SATISFACTION RATINGS
Work Trip Sample

Attribute Number	Attribute	Total Time	Walking Time	Waiting Time	Depend-ability	Chance of Seat	Comfort	Safety	Security	Privacy	Activity En Route	Flexi-bility	Multi-purpose	Total Cost	Parking Space
1	Total time	1.000													
2	Walking time	0.333	1.000												
3	Waiting time	0.581	0.267	1.000											
4	Dependability	0.605	0.212	0.536	1.000										
5	Chance of seat	0.151	0.065	0.222	0.168	1.000									
6	Comfort	0.284	0.152	0.271	0.299	0.341	1.000								
7	Safety	0.264	0.163	0.202	0.235	0.190	0.400	1.000							
8	Security	0.308	0.247	0.275	0.302	0.202	0.361	0.366	1.000						
9	Privacy	0.181	0.183	0.254	0.220	0.346	0.432	0.196	0.405	1.000					
10	Activity en route	0.198	0.135	0.202	0.229	0.248	0.357	0.305	0.223	0.364	1.000				
11	Flexibility	0.351	0.245	0.302	0.323	0.063	0.239	0.129	0.270	0.320	0.170	1.000			
12	Multipurpose	0.312	0.166	0.294	0.303	0.088	0.307	0.162	0.303	0.382	0.275	0.572	1.000		
13	Total cost	0.298	0.167	0.203	0.173	0.095	0.148	0.223	0.189	0.018	0.182	0.016	0.048	1.000	
14	Parking space	0.272	0.169	0.182	0.171	0.135	0.180	0.184	0.163	0.067	0.176	0.074	0.117	0.259	1.000

Sample Size: 718.
Critical r (5%) = 0.076.
Critical r (1%) = 0.099.

Table 4

MATRIX OF SIMPLE CORRELATION COEFFICIENTS FOR RELATIVE
(BART MINUS AUTO) ATTRIBUTE SATISFACTION RATINGS
Nonwork Trip Sample

Attribute Number	Attribute	Total Time	Walking Time	Waiting Time	Depend-ability	Chance of Seat	Comfort	Safety	Security	Privacy	Activity En Route	Flexi-bility	Multi-purpose	Total Cost	Parking Space
1	Total time	1.000													
2	Walking time	0.464	1.000												
3	Waiting time	0.651	0.430	1.000											
4	Dependability	0.618	0.386	0.684	1.000										
5	Chance of seat	0.129	0.103	0.058	0.080	1.000									
6	Comfort	0.152	0.101	0.223	0.223	0.072	1.000								
7	Safety	0.191	0.163	0.211	0.187	0.001	0.265	1.000							
8	Security	0.364	0.285	0.427	0.371	0.227	0.283	0.296	1.000						
9	Privacy	0.179	0.209	0.253	0.160	0.170	0.393	0.125	0.520	1.000					
10	Activity en route	0.142	0.167	0.062	0.041	0.059	0.311	0.388	0.141	0.239	1.000				
11	Flexibility	0.327	0.238	0.350	0.360	0.180	0.219	0.117	0.288	0.314	0.254	1.000			
12	Multipurpose	0.276	0.197	0.312	0.339	0.202	0.230	0.128	0.280	0.335	0.105	0.430	1.000		
13	Total cost	0.237	0.240	0.212	0.259	0.190	0.160	0.243	0.257	0.116	0.215	0.214	0.302	1.000	
14	Parking space	0.069	0.170	0.162	0.239	0.164	0.154	0.083	0.082	0.061	0.075	0.021	0.052	0.230	1.000

Sample Size: 143.
Critical r (5%) = 0.164.
Critical r (1%) = 0.215.

Table 5

MATRIX OF SIMPLE CORRELATION COEFFICIENTS FOR RELATIVE (BART MINUS BUS) ATTRIBUTE SATISFACTION RATINGS
Work Trip Sample

Attribute Number	Attribute	Total Time	Walking Time	Waiting Time	Depend-ability	Chance of Seat	Comfort	Safety	Security	Privacy	Activity En Route	Flexi-bility	Multi-purpose	Total Cost	Parking Space
1	Total time	1.000													
2	Walking time	0.485	1.000												
3	Waiting time	0.627	0.361	1.000											
4	Dependability	0.583	0.321	0.618	1.000										
5	Chance of seat	0.315	0.206	0.298	0.293	1.000									
6	Comfort	0.365	0.280	0.284	0.301	0.360	1.000								
7	Safety	0.375	0.277	0.327	0.342	0.274	0.511	1.000							
8	Security	0.314	0.264	0.227	0.233	0.360	0.463	0.466	1.000						
9	Privacy	0.269	0.220	0.212	0.229	0.454	0.511	0.362	0.484	1.000					
10	Activity en route	0.337	0.269	0.263	0.267	0.435	0.542	0.389	0.397	0.614	1.000				
11	Flexibility	0.322	0.179	0.329	0.320	0.021	0.176	0.217	0.020	0.067	0.118	1.000			
12	Multipurpose	0.288	0.202	0.286	0.294	0.051	0.225	0.254	0.127	0.068	0.185	0.520	1.000		
13	Total cost	0.357	0.228	0.317	0.306	0.101	0.169	0.258	0.216	0.092	0.130	0.144	0.239	1.000	
14	Parking space	0.152	0.177	0.110	0.121	0.226	0.233	0.231	0.257	0.245	0.242	-0.014	0.014	0.193	1.000

Sample Size: 1,518.
Critical r (5%) = 0.062.
Critical r (1%) = 0.081.

Table 6

MATRIX OF SIMPLE CORRELATION COEFFICIENTS FOR RELATIVE
(BART MINUS BUS) ATTRIBUTE SATISFACTION RATINGS
Nonwork Trip Sample

Attribute Number	Attribute	Total Time	Walking Time	Waiting Time	Depend-ability	Chance of Seat	Comfort	Safety	Security	Privacy	Activity En Route	Flexi-bility	Multi-purpose	Total Cost	Parking Space
1	Total time	1.000													
2	Walking time	0.579	1.000												
3	Waiting time	0.695	0.443	1.000											
4	Dependability	0.612	0.418	0.658	1.000										
5	Chance of seat	0.109	0.066	0.224	0.292	1.000									
6	Comfort	0.423	0.250	0.464	0.514	0.258	1.000								
7	Safety	0.222	0.262	0.164	0.337	0.186	0.468	1.000							
8	Security	0.267	0.179	0.284	0.358	0.224	0.426	0.375	1.000						
9	Privacy	0.279	0.139	0.205	0.244	0.413	0.291	0.398	0.401	1.000					
10	Activity en route	0.251	0.241	0.295	0.355	0.422	0.389	0.217	0.344	0.624	1.000				
11	Flexibility	0.244	0.109	0.342	0.263	0.043	0.193	0.307	0.180	0.174	0.179	1.000			
12	Multipurpose	0.207	0.233	0.276	0.307	0.010	0.284	0.305	0.137	0.138	0.198	0.268	1.000		
13	Total cost	0.280	0.284	0.256	0.274	0.061	0.217	0.364	0.268	0.134	0.132	0.339	0.204	1.000	
14	Parking space	0.160	0.042	0.193	0.322	0.050	0.009	0.173	0.026	0.095	0.048	0.285	0.061	0.297	1.000

Sample Size: 105.
Critical r (5%) = 0.192.
Critical r (1%) = 0.251.

Aside from variations introduced into the data by "halo" and other similar methodological causes, the high correlations shown in Tables 3 through 6 may be considered to arise for two reasons.

(1) "Semantic redundancies" occur because of respondents' interpretations of words used in the questionnaire to describe modal attributes. For example, "privacy" and "security" mean much the same thing to many respondents.

(2) Functional "supply side" relationships such as that between waiting time and dependability exist. (Undependable services give rise to long waiting times.)

For a combination of reasons (1) and (2), the typical traveler probably thinks in terms of a smaller number of decision factors or dimensions than the 14 attributes included in the questionnaire. So satisfaction ratings for some attributes, for example dependability and waiting time, may to a large extent be measuring the same dimension of the mode choice process. The problem of analyzing the basic dimensionality of a sample of observations on a large number of variables is one that can be addressed by factor analysis.

The technique of principal components analysis is one method of extracting factors. In analyzing our data, we applied a principal components analysis with varimax rotation to the relative attribute satisfaction ratings for each of the four samples 1, 12, 13, and 24. The first nine principal components in each sample accounted for at least 85% of the total variance in the original 14 variables. This confirms the hypothesis that fewer than 14 factors adequately describe the dimensionality of the modal choice decision. The results of the principal components analyses are summarized in Tables 7 to 10.

Most of the nine factors listed in Tables 7 to 10 have only one attribute with a factor-loading greater than 0.2. Where factors contain two or more attributes with factor-loadings at least equal to 0.2, the attributes are those which one would expect to be closely associated. For example, in Table 7, total travel time, waiting time, and dependability are the attributes with the highest loadings in factor 4. To this extent, the principal components analysis demonstrates the validity of the sample data. The close association between travel time and dependability is particularly noteworthy; in no case does the dependability attribute appear as a distinct factor.

In general, principal components analysis of a set of variables that are prospective regressors in a multiple regression equation may be used in alleviating the multicollinearity problem in two ways. First, the principal components solution can be used directly by replacing

Table 7

SUMMARY OF VARIMAX ROTATED FACTOR MATRIX
BART-Auto Mode Choice, Work Trips

Rotated Factor	Attributes with Absolute Factor Loadings $\geq$ 0.2	Absolute Factor Loadings	Factor Interpretation
1	Walking time	0.970	Walking time
2	Chance of Seat	0.967	Chance of seat
3	Total Cost	0.972	Total cost
4	Dependability	0.905	Total time
	Total time	0.285	
	Waiting time	0.227	
5	Parking space	0.976	Parking space
6	Safety	0.949	Safety
7	Activity en route	0.950	Activity en route
8	Flexibility	0.922	Flexibility
	Multipurpose	0.273	
9	Security	0.929	Security

Table 8

SUMMARY OF VARIMAX ROTATED FACTOR MATRIX
BART-Auto Mode Choice, Nonwork Trips

Rotated Factor	Attributes with Absolute Factor Loadings ≥ 0.2	Absolute Factor Loadings	Factor Interpretation
1	Walking time	0.945	Walking time
	Total time	0.214	
2	Parking space	0.982	Parking space
3	Flexibility	0.934	Flexibility
4	Safety	0.958	Safety
5	Multipurpose	0.938	Multipurpose
6	Comfort	0.952	Comfort
7	Chance of Seat	0.982	Chance of seat
8	Total time	0.878	Total time
	Waiting time	0.299	
	Dependability	0.275	
9	Total Cost	0.956	Total cost

Table 9

SUMMARY OF VARIMAX ROTATED FACTOR MATRIX
BART-Bus Mode Choice, Work Trips

Rotated Factor	Attributes with Absolute Factor Loadings ≥ 0.2	Absolute Factor Loadings	Factor Interpretation
1	Walking time	0.948	Walking time
	Total time	0.233	
2	Chance of seat	0.935	Chance of seat
3	Total cost	0.964	Total cost
4	Flexibility	0.942	Flexibility
	Multipurpose	0.253	
5	Parking space	0.975	Parking space
6	Security	0.911	Security
	Privacy	0.201	
7	Dependability	0.890	Total time
	Waiting time	0.272	
	Total time	0.245	
8	Safety	0.905	Safety
	Comfort	0.209	
9	Activity en route	0.881	Activity en route
	Privacy	0.264	
	Comfort	0.211	

Table 10

SUMMARY OF VARIMAX ROTATED FACTOR MATRIX
BART-Bus Mode Choice, Nonwork Trips

Rotated Factor	Attributes with Absolute Factor Loadings ≥ 0.2	Absolute Factor Loadings	Factor Interpretation
1	Walking time	0.836	Total time
	Total time	0.315	
2	Chance of seat	0.959	Chance of seat
	Activity en route	0.202	
3	Parking space	0.968	Parking space
	Dependability	0.204	
4	Security	0.936	Security
5	Multipurpose	0.963	Multipurpose
6	Flexibility	0.950	Flexibility
7	Total cost	0.944	Total cost
8	Comfort	0.889	Comfort
	Dependability	0.214	
9	Safety	0.906	Safety
	Comfort	0.208	

the observations on the original variables with the factor scores obtained by multiplying the original variables by the loadings given in the principal components factor matrix. These factor scores may then be used as the explanatory variables of the regression. The number of regressors is reduced (in our case, from 14 to 9), with a resulting savings in degrees of freedom. And, since the principal components are orthogonal, the multicollinearity problem is removed.

The coefficient of a regression equation can be interpreted as the magnitude of the effect on the dependent variable produced by a unit change in an explanatory variable. However, interpreting the coefficients of the factor score regression becomes difficult when the explanatory variable is a linear combination of the observed variables. Thus, while direct use of the principal components solution removes the multicollinearity problem, it is of little use in interpreting the coefficients as structural parameters.

An alternative use of the principal components analysis in reducing the effects of multicollinearity is to select a subset of the original variables based on their factor loadings in the principal components and perform the regression on this subset of observed variables. The resulting variables have lower intercorrelations, thus reducing the degree of multicollinearity, and at the same time, interpretation of the regression coefficients is simplified. An added advantage is that this method allows the inclusion or exclusion of any of the variables on grounds of model structure.

Use of principal components analysis in this latter way seems a more appropriate method than the former where the objective is to interpret the regression coefficients. Selecting a subset of the original variables so that highly correlated variables are omitted is the standard procedure for dealing with multicollinearity. Using the principal components analysis in this way merely provides a systematic and rational basis for selecting variables to be included. The matrices given in Tables 3 to 6 reveal that many of the correlations among the nine variables selected in each case are still statistically significant, but the very high correlations present among the original 14 variables are removed. Thus, the multicollinearity problem still exists, but its seriousness is lessened.

As noted earlier, many of the high correlations among the relative attribute satisfaction variables arise for "semantic" reasons; correlations are present because not all the words used to describe different attributes in the questionnaire are, in fact, able to identify independent dimensions of respondents' perceptions of the modes. These correlations may be viewed as arising because of a duplication of information--several attributes measure essentially the same factor as far as the respondents are concerned--and hence, discarding some of the variables to reduce multicollinearity is justified.

IV. BART-AUTOMOBILE CHOICE MODELS: ESTIMATION USING ATTRIBUTE SATISFACTION RATINGS

Having studied the data in some detail, we can now evaluate the mode choice decision by estimating and validating the mode-choice model specified in Chapter I. For each of the four samples, BART-auto choice work trips, BART-auto choice nonwork trips, BART-bus choice work trips, and BART-bus choice nonwork trips, four models are estimated using two different dependent choice variables and two different estimation methods. This chapter discusses the BART-auto choice models. Chapter V discusses the BART-bus choice models.

Model 1 takes the actual mode used (specified by values 0 or 1) as the dependent variable and relative satisfaction ratings for nine attributes (selected from the principal components analysis) as independent variables. The functional form of the model is

$$y = a_o + \sum_i a_i \Delta Q_i$$

This is referred to as the linear model. The parameters are estimated using the ordinary least-squares technique.

Model 2 is similar to Model 1 in structure and uses the same estimation method. The difference is that the dichotomous (0 or 1) dependent variable is now replaced by a continuous probability choice variable which indicates the fraction of time (in the last four weeks) that each of the two alternative modes was used. That is, the dependent variable can now take on any value in the range 0 to 1.

Model 3 takes the actual mode used as the dependent variable and attribute satisfaction ratings for nine attributes (again selected from the principal components analyses) as independent variables. This model has the functional form

$$y = \frac{1}{1 + e^{-(a_o + \sum_i a_i \Delta Q_i)}}$$

This is referred to as the logit model. The parameters are estimated using the maximum likelihood method.

Model 4 is similar to Model 3 except the dependent variable is the continuous probability choice variable.

Model estimation results for each of the four model forms are given in the following sections of the report.

BART-Auto Work Trips

This sample contains 718 individuals who made a modal choice between BART and automobile for their journeys to work across San Francisco Bay; 399 chose BART and 319 chose automobile. The results of model estimation are summarized in Table 11. In the table, the variables having significant coefficients are listed, with the corresponding t-statistic for the estimates shown in parenthesis.

Table 11 gives the multiple correlation coefficient, R^2, and the F-statistic for the linear models estimated by ordinary least-squares; and the likelihood ratio index (sometimes known as the pseudo-R^2), and the likelihood ratio statistic (similar to the least-squares F-statistic) for the logit models estimated by the maximum likelihood technique. In addition, the table shows relative coefficient values as computed by dividing all estimated coefficients by (usually) the largest coefficient. These ratios indicate the relative importance of the attributes in the mode choice decision. The percent of individuals correctly classified by their choice of mode is also shown. An individual is classified as a BART rider if his probability of choosing BART is predicted by the model as at least 0.5; otherwise, he is classified as an automobile user.

The results in Table 11 show that for BART-auto work trip choices, six attributes are significantly important in the mode-choice decision at the 5% level of significance (except for the total cost attribute in Model 4, which is at the 7% level). The same six attributes occur in all four models. All of the coefficients are of the expected sign. (The a priori expected sign is positive for all variables, since for every attribute one would expect an increase in satisfaction with BART relative to the alternative mode to result in an increased probability of BART being chosen.) The R^2 statistics associated with the linear models are both low (but still significant statistically), as is usually the case with dichotomous dependent variables. The motive in estimating Model 2, which has a continuous probability choice as the dependent variable, is to examine if this problem can be reduced. The explanatory power of the model might be expected to improve by specifying the dependent variable in continuous rather than dichotomous form simply for the reason that the continuous variable makes fuller use of the available information. As shown on Table 11, the values of R^2 differ very little for the models using the two different dependent variables.

One way of examining the validity of a mode-choice model is to predict the mode that an individual in the sample would use based on the estimated choice model, and compare it with the mode actually used. If the two choices match, the individual is considered correctly classified. The proportion of individuals correctly classified can then be used as a measure of how good the model is. For this sample, at least 71% of the travelers are correctly classified using any of the four models. Clearly, this is much better than what might be expected by a "chance"

Table 11

RESULTS OF MODEL ESTIMATION
BART-AUTO CHOICE, WORK TRIPS

Explanatory Variable	Estimated Coefficients (t-statistic)				Relative Importance of Attributes			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
1 Total time	0.034 (4.8)	0.019 (3.5)	0.180 (4.6)	0.084 (2.4)	0.756	0.576	0.723	0.542
2 Walking time	0.019 (2.7)	0.022 (4.2)	0.110 (2.7)	0.109 (3.0)	0.422	0.667	0.442	0.703
8 Security	0.029 (3.2)	0.024 (3.4)	0.180 (3.3)	0.121 (2.5)	0.644	0.727	0.723	0.781
10 Activity en route	0.015 (3.1)	0.012 (3.1)	0.083 (3.0)	0.054 (2.1)	0.333	0.364	0.333	0.348
11 Flexibility	0.045 (6.8)	0.033 (6.7)	0.249 (6.2)	0.155 (4.5)	1.000	1.000	1.000	1.000
13 Total cost	0.016 (2.7)	0.012 (2.6)	0.087 (2.5)	0.058 (1.8)	0.356	0.364	0.349	0.374
Constant	0.686	0.592	1.043	0.428				
R^2 or likelihood ratio index	0.265	0.268	0.232	0.117				
F or likelihood ratio statistic	42.7	37.2	230.8	116.2				
Percent correctly classified	73.8	71.9	73.5	71.7				

Sample size for model estimation: 718.

Model 1 is linear least squares method with a binary (0, 1) dependent variable.
Model 2 is linear least squares method with a continuous probability dependent variable.
Model 3 is logit maximum likelihood method with a binary (0, 1) dependent variable.
Model 4 is logit maximum likelihood method with a continuous probability dependent variable.

classification scheme, which would produce no better than a 50% correct classification.

Inspection of the "percent correctly classified" statistics shows that all four models give similar results. Unfortunately, the likelihood ratio index (computed for the logit models) cannot be compared with the R^2 statistic (computed for the linear models). There is no statistic which can be used to test the significance of the likelihood ratio index, nor is there an intuitive interpretation of the "goodness of fit" represented by it (as compared to R^2, the proportion of variation explained). The likelihood ratio statistic, however, can be used to indicate the significance of the estimated logit models since it is distributed asymptotically as chi-square with degrees of freedom equal to the number of coefficients estimated. For this sample, both logit models are significant. The F-statistic shows both linear models to be significant.

Based on Model 1, the linear model with binary dependent variable, the most important factors in the choice of BART or automobile for a work trip are, in order of importance:

- Flexibility to travel when you want
- Total door-to-door travel time
- Security from crime and unpleasant behavior of other people
- Walking time during the trip
- Total cost of door-to-door trip
- Availability to do what you want while traveling

Model 3, the logit model with binary dependent variable, yields the same importance ranking of the attributes as Model 1, and interestingly, the relative coefficients are very similar in magnitude. In other words, the linear model and the logit model give very similar estimates of relative attribute importance in modal choice.

The constant terms from the two models are also of the same magnitude. The constant term may be interpreted as describing the influence of those modal attributes and other influences not included explicitly as variables in the model. Note that in all models the constant term is positive. Thus, if all the relative attribute values in the model were zero (i.e., if BART and auto had identical ratings), then the models would predict a positive probability of BART being chosen. To illustrate, if all the relative attribute ratings are equal to zero, the linear model gives a probability of 0.686 that BART will be chosen, compared to 0.739 for the logit model.

The closeness of the linear and logit model results seem to indicate that the data lie on a portion of the logistic curve which is approximately linear. The same observation can be made when one compares Models 2 and 4.

BART-Auto Nonwork Trips

This sample contains 143 individuals who made a modal choice between BART and automobile for a nonwork journey across San Francisco Bay; 90 chose BART and 53 chose automobile. Results of the model estimation are summarized in Table 12. As shown, using the continuous probability choice variable as dependent variable does not give a better explanation of modal choice; quite the contrary. The dichotomous dependent variable models (Models 1 and 3) both include the same three attributes as significant explanatory variables in the following order of importance:

- Total door-to-door travel time
- Ability to combine different purposes in a single trip
- Ability to find a place to park

The coefficients all have the expected sign and are significant at the 5% level (except for parking space which is significant at the 7% level). Both the F-statistic for Model 1 and the likelihood ratio statistic for Model 3 show the models are significant. More than 72% of individuals are correctly classified. Note that for nonwork trips, a much smaller number of attributes have significant coefficients than work trips. This is primarily because of the relatively small number of observations in the nonwork trip sample.

As with the work trip choice models, the relative importance of the significant attributes as given in Models 1 and 3 in the nonwork case is very close in magnitude, suggesting again that the data lie on a linear portion of the logistic curve.

Table 12

RESULTS OF MODEL ESTIMATION
BART-AUTO CHOICE, NONWORK TRIPS

Explanatory Variable	Estimated Coefficients (t-statistic)				Relative Importance of Attributes			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
1 Total time	0.059 (4.4)	--	0.518 (3.9)	--	1.000	--	1.000	--
12 Multipurpose	0.043 (2.6)	0.045 (3.2)	0.245 (2.6)	0.188 (2.4)	0.729	1.000	0.770	1.000
14 Parking space	0.021 (1.9)	--	0.113 (1.8)	--	0.356	--	0.355	--
Constant	0.719	0.517	1.212	0.073				
R^2 or likelihood ratio index	0.225	0.069	0.232	0.046				
F or likelihood ratio statistic	13.5	10.4	46.0	9.2				
Percent correctly classified	72.0	61.5	72.7	61.5				

Sample size for model estimation: 143.

Model 1 is linear least squares method with a binary (0, 1) dependent variable.
Model 2 is linear least squares method with a continuous probability dependent variable.
Model 3 is logit maximum likelihood method with a binary (0, 1) dependent variable.
Model 4 is logit maximum likelihood method with a continuous probability dependent variable.

V. BART-BUS CHOICE MODELS: ESTIMATION USING ATTRIBUTE SATISFACTION RATINGS

This chapter estimates work and nonwork models for BART-bus choices for each of the same four model forms described in Chapter IV.

BART-Bus Work Trips

This sample contains 1,518 travelers who made a modal choice between BART and bus for a journey to work across San Francisco Bay. Of the total, 717 chose BART and 801 chose bus. Results of the model estimation are shown in Table 13. Comments made in Chapter IV about the significance of coefficients also apply in this chapter.

As shown in the table, eight attributes have significant coefficient estimates. The relative importance coefficients obtained from Models 1 (linear) and 3 (logit) are close except in the case of total cost (although this attribute is still rated as one of the three most important factors in both models). The most important attributes given by Model 1 are, in order:

- Total door-to-door travel time
- Walking time during the trip
- Total cost of door-to-door trip
- Safety from accident or injury
- Security from crime and unpleasant behavior of other people
- Ability to do what you want while traveling
- Ability to find a place to park
- Flexibility to travel when you want

BART-Bus Nonwork Trips

This sample contains 105 individuals who made a modal choice between BART and bus for a nonwork journey across San Francisco Bay: 48 chose BART and 57 chose bus. Results of model estimation are shown in Table 14. Only two attributes have significant coefficients:

- Total door-to-door travel time
- Safety from accident or injury

Table 13

RESULTS OF MODEL ESTIMATION
BART-BUS CHOICE, WORK TRIPS

Explanatory Variable	Estimated Coefficients (t-statistic) Model 1	Model 2	Model 3	Model 4	Relative Importance of Attributes Model 1	Model 2	Model 3	Model 4
1 Total time	0.065 (14.5)	0.059 (15.6)	0.467 (11.6)	0.330 (10.3)	1.000	1.000	1.000	1.000
2 Walking time	0.040 (9.2)	0.030 (8.1)	0.337 (8.7)	0.188 (6.1)	0.615	0.508	0.722	0.570
3 Safety	0.022 (3.3)	0.018 (3.4)	0.242 (4.0)	0.131 (2.8)	0.338	0.305	0.518	0.397
8 Security	0.013 (2.1)	--	0.125 (2.4)	--	0.200	--	0.268	--
10 Activity en route	0.013 (2.6)	0.015 (3.4)	0.120 (3.5)	0.076 (2.6)	0.200	0.254	0.257	0.230
11 Flexibility	0.007 (1.7)	0.005 (1.6)	0.113 (3.9)	0.077 (3.2)	0.108	0.085	0.242	0.233
13 Total cost	0.039 (7.1)	0.040 (8.4)	0.439 (8.5)	0.305 (7.4)	0.600	0.678	0.940	0.924
14 Parking space	0.010 (2.3)	0.009 (2.4)	0.085 (2.5)	0.052 (1.8)	0.154	0.153	0.182	0.158
Constant	0.544	0.593	0.380	0.589				
R^2 or likelihood ratio index	0.442	0.448	0.452	0.298				
F or likelihood ratio statistic	149.6	174.8	951.4	626.2				
Percent correctly classified	82.6	81.4	83.3	81.4				

Sample size for model estimation: 1,518.

Model 1 is linear least squares method with a binary (0, 1) dependent variable.
Model 2 is linear least squares method with a continuous probability dependent variable.
Model 3 is logit maximum likelihood method with a binary (0, 1) dependent variable.
Model 4 is logit maximum likelihood method with a continuous probability dependent variable.

Table 14

RESULTS OF MODEL ESTIMATION
BART-BUS CHOICE, NONWORK TRIPS

Explanatory Variable	Estimated Coefficients (t-statistic)				Relative Importance of Attributes			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
1 Total time	0.100 (7.1)	0.058 (4.6)	1.169 (4.1)	0.332 (3.1)	0.758	0.436	0.774	0.403
7 Safety	0.132 (4.9)	0.133 (5.6)	1.511 (4.0)	0.824 (3.5)	1.000	1.000	1.000	1.000
Constant	0.474	0.470	-0.249	-0.198				
R^2 or likelihood ratio index	0.479	0.397	0.536	0.234				
F or likelihood ratio statistic	46.9	33.6	78.0	34.1				
Percent correctly classified	86.7	83.8	86.7	83.8				

Sample size for model estimation: 105.

Model 1 is linear least squares method with a binary (0, 1) dependent variable.
Model 2 is linear least squares method with a continuous probability dependent variable.
Model 3 is logit maximum likelihood method with a binary (0, 1) dependent variable.
Model 4 is logit maximum likelihood method with a continuous probability dependent variable.

Once again, the dichotomous dependent variable models (Models 1 and 3) explain better than the models that use a continuous probability variable as the dependent variable (Models 2 and 4). Also, the relative importances of the significant attributes as estimated by the linear least-squares method are similar to those obtained using maximum likelihood logit estimation.

Conclusions about Model Forms

Using a continuous probability dependent variable does not seem to produce a better explanatory model than the dichotomous (0 or 1) choice variable. This is somewhat surprising. Two reasons can be hypothesized:

1. Only a relatively short time (six weeks) elapsed between the start of BART transbay service and the survey. As a result, the distribution of choices (as represented by trip frequencies in the previous four weeks) may not be typical of "steady state" travel behavior.

2. Although the questionnaire specifically asked how often the respondent used a certain mode for the same type of trip in the last four weeks, respondents might have given frequencies for all trips.

Results of model estimation for all four samples indicate that the nonlinear logit model produces coefficient estimates of relative importance similar to those produced by the linear least-squares model. For each sample, the same attributes appear as statistically significant using either linear or logit model form. Differences in the number of attributes included in the results for the different samples can be partly attributed to the sample sizes. The BART-bus models provide better estimation results (in terms of goodness-of-fit) than the BART-automobile models.

VI. COMPARISON OF ESTIMATED AND REPORTED ATTRIBUTE IMPORTANCE

This chapter compares the relative attribute importances estimated by the models (as summarized in Chapters IV and V) with the attribute importance ratings reported directly by respondents in the questionnaire. The former are referred to as <u>inferred</u> importances, and the latter as <u>reported</u> importances.

Reported importances are computed from a tally of the number of times each attribute is mentioned by a respondent as one of the four most important factors in his choice of a particular mode.

BART-Auto Choice

Table 15 shows the reported and inferred importance ranking for people making BART-auto choices for work and nonwork trips. The differences between the two rankings may be attributable to one or more of three causes:

1. The method of computing reported importance ratings may give misleading results. Specifically, many individuals choose one mode over the other mainly because of one or maybe two factors. So even though these individuals may list other attributes as important (to provide four as requested by the questionnaire), these additional attributes may not enter into the mode choice decision in a significant way.

2. The actual behavior of the respondent may be inconsistent with his responses to the questionnaire.

3. The coefficients of the models may not truly yield "importances" in the same sense as implied by the wording of the questionnaire.

However, comparing the listings in total, much coincidence of the attributes appears. Table 15 shows that, for the work trip sample, the importance rankings of attributes are fairly close, with total time and flexibility ranking as two of the three most important attributes in both cases. As shown in Table 11, attributes with rankings lower than number three are only about a third as important as flexibility. This suggests that these other attributes, although statistically significant, may not have a large influence on actual choice of mode.

For nonwork trips, the most important factor, both reported and inferred, is total travel time. The multipurpose and parking space attributes, although inferred to be important, appear much lower down on the list of reported importance rankings.

Table 15

REPORTED[a] AND INFERRED[b] IMPORTANCE RANKING
BART-AUTO CHOICE

Importance Ranking	Work Trips		Nonwork Trips	
	Reported	Inferred	Reported	Inferred
1	Total time	Flexibility	Total time	Total time
2	Total cost	Total time	Total cost	Multipurpose
3	Flexibility	Security	Flexibility	Parking space
4	Activity en route	Walking time	Comfort	--
5	Safety	Total cost	Safety	--
6	Parking space	Activity en route	Parking space	--
7	Chance of seat	--	Multipurpose	--
8	Walking time	--	Walking time	--
9	Security	--	Chance of seat	--

a. Based on the frequency with which an attribute is mentioned as one of the four most important factors in respondents' mode-choice decisions.
b. Based on model coefficient estimates (see Tables 11 and 12).

BART-Bus Choice

Table 16 presents the reported and inferred importance rankings of attributes for people making a BART-bus choice for work and nonwork trips. Again, for work trips, many of the attributes may not strongly influence modal choice, although they have statistically significant coefficients. As shown on Table 13, only walking time and total cost have high importance coefficients relative to total time. The other attributes are only about one-fifth as important as total time. Once again, two of the top three attributes inferred as important are also reported as important. Note that all three attributes are time and cost variables typically used in "conventional" mode choice models.

For nonwork trips, only safety and total time have significant coefficients as estimated from the data, with total time about three-quarters as important as safety. In the ranking of reported importance, total time is also one of the two most important factors.

Note that chance of a seat is high in the ranking of reported importance, but not in the ranking of inferred importance. This may be explained as follows. Having a seat (or conversely, the fear of not having a seat) is important as implied by the reported ranking. But most people actually do have a seat for their trip (virtually all bus riders and most BART riders do), so the attribute does not appear as important on the inferred list because the data contain very little variation in the satisfaction ratings. This illustrates what may be the major shortcoming of the basic choice model as specified in Chapter I. Namely, the coefficients of the model (the importances) are not independent of the values taken on by the explanatory variables (the relative satisfaction ratings) as assumed in the model formulation. Rather, the coefficients of the model tend to identify as important those attributes for which there is a large difference in satisfaction between the modes, and to identify as unimportant those attributes for which there is little difference in satisfaction.

Note also that dependability of on-time arrival does not appear in the importance rankings, although intuitively this attribute is an important factor in travelers' choices between BART and the alternative modes. As analyzed in Chapter III, the reason for this is that travel time and dependability variables are highly correlated. (In Table 3 of Chapter III, for example, the correlation coefficient between total time and dependability is the highest in the entire 14-by-14 matrix.) Consequently, it is not possible to separate out the effects of travel time and dependability with any confidence, and dependability is not included as a separate variable in the model. However, it is clear that travel time and dependability are perceived by travelers as closely related, so that the travel time variable included in the model (which appears as important in all columns of Tables 15 and 16) effectively includes the influence of dependability.

Table 16

REPORTED[a] AND INFERRED[b] IMPORTANCE RANKING
BART-BUS CHOICE

Importance Ranking	Work Trips		Nonwork Trips	
	Reported	Inferred	Reported	Inferred
1	Total time	Total time	Total time	Safety
2	Chance of seat	Walking time	Total cost	Total time
3	Total cost	Total cost	Security	--
4	Flexibility	Safety	Chance of seat	--
5	Walking time	Activity en route	Flexibility	--
6	Activity en route	Security	Safety	--
7	Safety	Parking space	Walking time	--
8	Security	Flexibility	Activity en route	--
9	Parking space	--	Parking space	--

a. Based on the frequency with which an attribute is mentioned as one of the four most important factors in respondents' mode-choice decisions.
b. Based on model coefficient estimates (see Tables 13 and 14).

Relative Importance for All Attributes

The analyses of earlier sections have confined themselves to a subset of 9 of the 14 attributes included in the survey questionnaire. This was done to reduce the effects of multicollinearity in model estimation. Table 17 summarizes the reported importance ratings for all 14 attributes, grouped for automobile, bus, and BART travelers (irrespective of their alternative mode choice). The data summarized in the table are for all trip purposes and for all respondents to the transbay surveys (not screened or edited as described in Chapter III). The table essentially restates the results given in Tables 15 and 16. It also illustrates the point made in the preceding section, that some attributes which were not included in the models because of multicollinearity problems--such as dependability and waiting time--are apparently important in many mode choices.

Table 17

RELATIVE IMPORTANCE OF TRAVEL FACTORS IN TRANSBAY MODAL CHOICE

Automobile Travelers			Bus Travelers			BART Travelers		
Factor	Number of Times Mentioned[a]	Relative Importance Index[b]	Factor	Number of Times Mentioned[a]	Relative Importance Index[b]	Factor	Number of Times Mentioned[a]	Relative Importance Index[b]
Flexibility	46,360	100.0	Total time	11,530	100.0	Total time	11,680	100.0
Total time	45,370	97.9	Dependability	9,720	84.3	Comfort	9,630	82.4
Multipurpose	37,800	81.5	Chance of seat	8,770	76.1	Total cost	9,570	81.9
Dependability	37,450	80.8	Waiting time	7,230	62.7	Dependability	7,670	65.7
Waiting time	23,000	49.6	Total cost	6,850	59.4	Flexibility	5,880	50.3
Total cost	18,470	39.8	Walking time	4,270	37.0	Safety	5,580	47.8
Activity en route	13,660	29.5	Flexibility	3,170	27.5	Activity en route	4,930	42.2
Security	11,550	24.9	Safety	2,810	24.4	Waiting time	4,770	40.8
Privacy	10,280	22.2	Comfort	2,410	20.9	Parking space	3,980	34.1
Walking time	8,670	18.7	Security	1,970	17.1	Chance of seat	3,980	34.1
Parking space	7,390	15.9	Activity en route	1,900	16.5	Walking time	3,680	31.5
Safety	6,830	14.7	Parking space	1,320	11.4	Security	3,340	28.6
Chance of seat	6,450	13.9	Multipurpose	870	7.5	Multipurpose	1,310	11.2
Comfort	5,310	11.5	Privacy	670	5.8	Privacy	660	5.7

Note: Factors are listed in order of the most important to least important.

a. The rankings of factor importance are based on the aggregate of the times each factor was mentioned by survey respondents as being either the first, second, third, or fourth most important reason in their choice of mode.

b. The relative importance index was calculated by dividing the number of times a factor was mentioned by the number of times the most important factor was mentioned and then multiplying by 100.

Source: BART Impact Program Surveys of Transbay Travel, October 1974.

VII. CHOICE MODELS USING REPORTED TIME AND COST

Table 18 shows results of model estimation using reported total time and total cost values as explanatory variables and actual mode chosen as the dependent variable. Both a linear least-squares model and a logit model are estimated to provide a comparison with models estimated using attribute satisfaction ratings as the explanatory variables (Chapters IV and V). Comparing Table 18 and Tables 11 through 14 reveals that, in terms of goodness of fit, the attribute satisfaction-based models are about the same as the time-cost (attribute value-based) models for mode choices between BART and automobile. For mode choices between BART and bus, the attribute satisfaction-based models appear to be better than the attribute value-based models. This could be due to the relatively small variation in total time and total cost on transbay BART and bus for most travelers. But it also suggests that, particularly in a choice between BART and bus, factors other than time and cost are indeed important determinants of mode choice.

Both total time and total cost have the expected signs and significant coefficients, except for the BART-bus nonwork sample where only the total time variable is significant. However, the latter model is relatively unimportant because of the small sample size available. The ratios between the total time and total cost coefficients are generally similar for the linear and logit models. For the logit model, the value of time savings implied by the ratio of the cost coefficient to the time coefficient is $3.69 per hour for people making BART-auto work-trip choices, but only $1.50 per hour for people making nonwork-trip choices. The relative magnitudes of these values of time savings estimates are as expected intuitively.

Correlations between the actual reported values of the time and cost attributes and the satisfaction ratings assigned by respondents are analyzed in Chapter XII.

Table 18

SUMMARY OF MODEL ESTIMATION USING
REPORTED TIME AND COST VARIABLES

Mode Choice	Trip Type	Explanatory Variable	Coefficient Estimates (t): Linear Model	Coefficient Estimates (t): Logit Model
1. BART-Auto	Work	Total time	-0.007 (9.4)	-0.043 (7.9)
		Total cost	-0.001 (11.3)	-0.007 (9.2)
		Constant	0.559	0.366
Statistics	R^2 or likelihood ratio index		0.293	0.271
	F or likelihood ratio statistic		148.0	270.0
	Percent correctly classified		73.4	73.8
2. BART-Auto	Nonwork	Total time	-0.004 (2.7)	-0.030 (2.9)
		Total cost	-0.001 (6.1)	-0.012 (5.0)
		Constant	0.579	0.555
Statistics	R^2 or likelihood ratio index		0.291	0.333
	F or likelihood ratio statistic		28.7	66.1
	Percent correctly classified		81.8	81.8
3. BART-Bus	Work	Total time	-0.012 (20.0)	-0.071 (15.9)
		Total cost	-0.003 (8.4)	-0.016 (7.9)
		Constant	0.511	0.091
Statistics	R^2 or likelihood ratio index		0.246	0.215
	F or likelihood ratio statistic		247.7	452.4
	Percent correctly classified		73.8	73.4
4. BART-Bus	Nonwork	Total time	-0.009 (4.2)	-0.045 (3.6)
		Constant	0.445	0.260
Statistics	R^2 or likelihood ratio index		0.145	0.119
	F or likelihood ratio statistic		17.4	17.3
	Percent correctly classified		66.7	66.7

VIII. BART-AUTOMOBILE CHOICE MODELS: WORK TRIPS STRATIFIED BY BART STATION

Model Estimation

In this chapter, and Chapters IX, X, and XI, the journey-to-work mode choice decision is studied in more detail. Individuals are first classified into groups according to the East Bay BART station they use for a work trip to San Francisco (or would use if they were to make the trip on BART). Recognizing the importance of total travel time on mode choice, and to allow differences in travel behavior on the lines of the System to be analyzed, the stations are grouped according to their published travel time from the Montgomery Street BART station as follows:

Group 1. Oakland Stations Within 25 Minutes of Montgomery Street

MacArthur
19th Street Oakland
12th Street Oakland
Lake Merritt
Oakland West

Group 2. Richmond Line Stations Within 25 Minutes of Montgomery Street

North Berkeley
Berkeley
Ashby

Group 3. Concord Line Stations Within 25 Minutes of Montgomery Street

Orinda
Rockridge

Group 4. Fremont Line Stations within 25 minutes of Montgomery Street

Bay Fair
San Leandro
Coliseum
Fruitvale

Group 5. Richmond Line Stations More Than 25 Minutes From Montgomery Street

Richmond
El Cerrito del Norte
El Cerrito Plaza

Group 6. Concord Line Stations More Than 25 Minutes From Montgomery Street

Concord
Pleasant Hill
Walnut Creek
Lafayette

Group 7. Fremont Line Stations More Than 25 Minutes From Montgomery Street

Fremont
Union City
South Hayward
Hayward

This stratification allows examination of the mode choice decision as it is affected by the different transportation system characteristics of the BART corridors, such as BART and bus service levels and highway congestion, and the implicit influence of the different socioeconomic characteristics of the residents in the corridors.

Of the 718 individuals who choose between BART and automobile for a transbay work trip, 114 (16%) are from Station Group 1; 71 (10%) from Station Group 2; 123 (17%) from Station Group 3; 83 (12%) from Station Group 4; 38 (5%) from Station Group 5; 210 (29%) from Station Group 6; and 79 (11%) from Station Group 7. Linear and logit models are estimated for each of the station groups, and results of these model estimations are presented in Table 19. The corresponding inferred relative importance ratings of attributes (derived by taking ratios of the model coefficients) are shown in Table 20. Only coefficients which are significantly different from zero at the 5% significance level are included in the tables. As shown, the estimated coefficients remain fairly stable across station groups in most cases, even though sample sizes are much smaller than in the models summarized in Chapters IV and V. This provides added confidence in the validity of the models. As before, the relative importance coefficients of attributes as estimated by the linear model do not differ much from those estimated by the logit model. However, owing to the relatively small sample sizes, only a few variables (typically two or three) appear in the models as statistically significant. As an aid in interpreting Tables 19 and 20, Table 21 summarizes the actual differences in average satisfaction ratings (BART minus automobile) for each station group. Note that the tables show averages for the samples and do not reflect the within-sample variances which are important in model estimation.

Table 19

RESULTS OF MODEL ESTIMATION
BART-AUTO CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

	Estimated Coefficient (t-statistic)													
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1. Total time	0.071 (5.2)	0.479 (4.1)	0.064 (3.0)	0.377 (2.7)	0.054 (2.9)	0.290 (2.8)	0.051 (2.6)	0.231 (2.4)	0.087 (3.3)	0.737 (2.3)	--	--	--	--
2. Walking time	--	--	--	--	0.039 (2.3)	0.222 (2.3)	--	--	--	--	0.041 (3.6)	0.240 (3.2)	--	--
7. Safety	--	--	0.074 (2.6)	0.485 (2.5)	--	--	--	--	--	--	--	--	--	--
8. Security	0.046 (2.3)	0.384 (2.3)	--	--	--	--	--	--	--	--	--	--	0.063 (2.8)	0.414 (2.3)
10. Activity en route	0.033 (2.9)	0.230 (2.7)	--	--	--	--	--	--	--	--	--	--	--	--
11. Flexibility	--	--	--	--	0.040 (2.7)	0.217 (2.5)	--	--	0.092 (3.1)	0.741 (2.4)	0.073 (7.3)	0.433 (5.6)	0.033 (2.2)	0.220 (1.8)
13. Total cost	--	--	--	--	--	--	--	--	--	--	0.029 (2.8)	0.165 (2.4)	--	--
Constant	0.678	1.175	0.377	-0.750	0.688	0.999	0.633	0.589	0.872	3.320	0.665	0.984	0.827	1.888
R^2 or likelihood ratio index	0.342	0.383	0.253	0.276	0.232	0.194	0.075	0.087	0.396	0.461	0.332	0.283	0.169	0.337
F or likelihood ratio statistic	19.1	60.6	11.5	27.2	12.0	33.1	6.6	10.0	11.5	24.3	32.6	82.3	7.7	36.9
Percent correctly classified	78.9%	78.9%	69.0%	71.8%	71.5%	71.5%	65.1%	65.1%	84.2%	84.2%	74.3%	73.8%	81.0%	79.7%
Sample size	114		71		123		83		38		210		79	

a. Definition of the station groups is given in the text.

Table 20

INFERRED RELATIVE IMPORTANCE OF ATTRIBUTES
BART-AUTO CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

	Relative Importance of Attributes													
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1. Total time	1.000	1.000	0.865	0.777	1.000	1.000	1.000	1.000	0.946	0.994	--	--	--	--
2. Walking time	--	--	--	--	0.722	0.766	--	--	--	--	0.562	0.554	--	--
7. Safety	--	--	1.000	1.000	--	--	--	--	--	--	--	--	--	--
8. Security	0.648	0.800	--	--	--	--	--	--	--	--	--	--	--	--
10. Activity en route	0.465	0.480	--	--	--	--	--	--	--	--	--	--	1.000	1.000
11. Flexibility	--	--	--	--	0.741	0.749	--	--	1.000	1.000	1.000	1.000	0.524	0.533
13. Total cost	--	--	--	--	--	--	--	--	--	--	0.397	0.380	--	--

a. Definition of the station groups is given in the text.

Table 21

DIFFERENCE IN ATTRIBUTE SATISFACTION RATINGS BETWEEN ALTERNATIVE MODES
BART-AUTO CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

Explanatory Variable	Difference in Attribute Satisfaction Ratings[b]						
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Total time	-0.61	-2.35	-1.07	-0.60	-2.79	-0.78	0.43
Walking time	-0.42	-1.03	-0.85	-0.92	-1.42	-0.30	-0.42
Chance of seat	-1.78	-2.79	-3.72	-1.36	-2.97	-3.33	-1.30
Safety	1.79	1.70	1.47	2.14	1.50	1.98	2.15
Security	-0.25	-0.83	-0.75	-0.69	-1.63	-0.71	-0.20
Activity en route	1.32	1.25	0.25	0.72	-0.92	0.40	1.57
Flexibility	-2.04	-3.39	-2.50	-2.52	-3.42	-1.83	-1.68
Total cost	1.93	1.30	1.50	1.53	1.08	1.00	1.06
Parking space	1.10	1.20	0.33	1.49	1.16	-0.57	0.49

a. Definition of the station groups is given in the text.
b. BART attribute satisfaction rating minus automobile attribute satisfaction rating (positive number indicates BART perceived favorably).

Group 1 (MacArthur, 19th Street, 12th Street, Lake Merritt, Oakland West)

Of the 114 individuals in this sample, 76 (67%) actually use BART and 38 (33%) use automobile. The model indicates that these individuals consider total door-to-door travel time as most important, followed by security and activity en route. Stations in this group are located in central Oakland.

Group 2 (North Berkeley, Berkeley, Ashby)

Of the 71 individuals in this group, 25 (35%) actually use BART and 46 (65%) use automobile. These individuals are estimated to consider safety as most important in their choice of travel mode, with total door-to-door travel time not far behind. The fact that a large percentage of travelers in this group chooses automobile probably reflects the lack of direct BART service between these stations and San Francisco. This causes an increase in total travel time because a transfer to another train (and hence extra waiting time) is necessary. Why safety should be particularly important to Richmond Line travelers is not clear.

Group 3 (Orinda, Rockridge)

The 123 individuals in this group are split almost evenly between the two modes with 61 choosing BART and 62 using automobile. For this group, total door-to-door travel time is the most important factor in mode choice, with walking time and flexibility also important. A closer look at the distribution of BART riders using these two stations reveals that the BART riders come mostly from the Orinda BART station (60% of the BART riders) whereas automobile users are mostly people with origins located around the Rockridge BART station. This may reflect the effects of the congestion on Highway 24 through the Caldecott Tunnel (which Orinda, but not Rockridge automobile users have to face).

Group 4 (Fruitvale, Coliseum, San Leandro, Bay Fair)

Of the 83 individuals in this group, 50 (60%) actually use BART and 33 (40%) choose automobile as their mode of travel to work. To these people, total door-to-door travel time is again the single most important consideration in their mode choice decisions. A station-by-station breakdown of mode choices shows that the proportion of BART riders increases from 41% for Fruitvale to 58% for Coliseum, 65% for San Leandro, and 79% for Bay Fair. This may reflect the increasing advantage in total travel time for BART (with its own right-of-way) over automobile as the commute distance (on congested highways) increases.

Group 5 (Richmond, El Cerrito del Norte, El Cerrito Plaza)

Relatively few people commute from these areas to San Francisco. Of the 38 individuals in this group, only 12 (32%) use BART. The two most decisive factors in their mode choices are total door-to-door travel time and flexibility to leave when they want to. Once again, the lack of direct BART service between these stations and San Francisco stations may explain the use of automobile by most people in this group.

Group 6 (Concord, Pleasant Hill, Walnut Creek, Lafayette)

Of the 210 travelers in this sample 115 (55%) actually use BART and 95 (45%) use automobile. Flexibility is indicated by the model as the primary consideration in the choice of mode, with walking time and total cost as the next most important considerations. Flexibility and walking time are attributes favoring the use of automobile, while total cost favors the use of BART.

Group 7 (Hayward, South Hayward, Union City, Fremont)

There are 79 travelers in this group of whom 60 (76%) use BART and only 19 (24%) use automobile. Security appears to be an important factor in mode choice, although it is difficult to explain why this should be. Flexibility is also indicated as important in the choice of travel mode.

IX. BART-BUS CHOICE MODELS: WORK TRIPS STRATIFIED BY BART STATION

A total of 1,518 individuals make up the sample of travelers who choose between BART and bus for a transbay work trip. Of these, 158 (10%) are from Station Group 1; 157 (10%) from Station Group 2; 137 (9%) from Station Group 3; 193 (13%) from Station Group 4; 115 (8%) from Station Group 5; 643 (42%) from Station Group 6; and 115 (8%) from Station Group 7.

Table 22 shows the results of model estimation (including only coefficients significant at the 5% significance level) and Table 23 shows the inferred relative importance of attributes. As before, most of the attribute coefficients remain fairly stable across station groups, and the linear and logit models provide similar estimates of relative importance. Total travel time appears as an important factor in all but one case. Walking time also appears as an important factor in all cases, underlining the importance of access to the "line-haul" transit mode in travel choice. Bus, with its much closer effective station spacing, clearly has the advantage over BART in this respect. Table 24 summarizes the actual differences in average satisfaction ratings (BART minus bus) for each station group.

Group 1 (MacArthur, 19th Street, 12th Street, Lake Merritt, Oakland West)

A total of 158 travelers in the sample comes from this group; 57 (36%) of these use BART and 101 (64%) use bus. For these individuals, total travel time, walking time, chance of seat, and security are indicated as the important factors in choosing between BART and bus. The areas represented by this station group generally have good AC Transit transbay bus service in commute hours, and both total travel time and walking time are lower by bus than by BART for most travelers.

Because these BART stations are the last East Bay stations before crossing the Bay and several of them are transfer points for the Richmond Line travelers, crowding on BART trains at these stations is common in commute hours. This may explain why chance of a seat and security from unpleasant behavior also appear as important considerations in the choice between bus and BART.

Group 2 (North Berkeley, Berkeley, Ashby)

Of the 157 travelers in this group, only 28 (18%) actually use BART and 129 (82%) use bus. The factors considered by this group as most important in modal choices are security, total travel time, walking time, and activity en route. Since these stations do not have direct transbay BART service, BART riders have to transfer between trains in Oakland. On the

Table 22

RESULTS OF MODEL ESTIMATION
BART-BUS CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

Explanatory Variable	Estimated Coefficients (t-statistic)													
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1. Total time	0.065 (6.1)	0.827 (3.9)	0.035 (2.5)	0.524 (2.5)	0.106 (7.0)	0.796 (5.0)	0.076 (6.4)	0.660 (4.7)	--	--	0.028 (2.4)	0.228 (2.5)	0.062 (4.7)	0.642 (3.7)
2. Walking time	0.034 (3.0)	0.374 (2.3)	0.035 (2.7)	0.550 (2.6)	0.033 (2.6)	0.269 (2.6)	0.036 (2.9)	0.480 (3.0)	0.036 (2.6)	0.512 (2.4)	0.044 (6.6)	0.352 (6.1)	0.028 (2.0)	0.252 (1.5)
5. Chance of seat	0.036 (3.4)	0.243 (1.9)	--	--	--	--	--	--	0.028 (2.5)	0.331 (2.4)	--	--	--	--
7. Safety	--	--	--	--	--	--	--	--	--	--	0.016 (1.6)	0.224 (2.6)	0.070 (3.2)	0.769 (2.8)
8. Security	0.050 (3.0)	0.625 (2.2)	0.057 (3.4)	0.532 (2.7)	--	--	0.057 (3.7)	0.550 (3.3)	--	--	0.028 (2.8)	0.285 (3.4)	--	--
10. Activity en route	--	--	0.026 (2.0)	0.338 (1.9)	--	--	--	--	--	--	0.031 (4.9)	0.201 (4.2)	--	--
11. Flexibility	--	--	--	--	--	--	0.022 (2.5)	0.262 (2.7)	0.026 (2.4)	0.308 (1.9)	--	--	--	--
13. Total cost	--	--	--	--	--	--	0.022 (1.6)	0.305 (2.2)	--	--	0.042 (4.1)	0.529 (5.0)	0.046 (3.0)	0.516 (2.7)
14. Parking space	--	--	--	--	--	--	--	--	0.051 (3.2)	0.542 (2.9)	0.030 (5.1)	0.240 (4.9)		
Constant	0.498	-0.295	0.295	-1.020	0.662	1.117	0.432	-0.660	0.290	-1.172	0.687	1.240	0.624	0.901
R^2 or likelihood ratio index	0.604	0.673	0.337	0.634	0.418	0.423	0.525	0.574	0.294	0.652	0.435	0.458	0.479	0.583
F or likelihood ratio statistic	58.3	147.4	19.3	137.9	48.2	80.2	41.3	153.5	11.4	103.9	69.9	407.9	25.3	92.9
Percent correctly classified	89.9%	89.2%	87.3%	89.8%	80.3%	80.3%	86.1%	84.5%	89.6%	91.3%	83.4%	83.7%	87.0%	87.8%
Sample size	158		157		137		193		115		643		115	

a. Definition of the station groups is given in the text.

Table 23

INFERRED RELATIVE IMPORTANCE OF ATTRIBUTES
BART-BUS CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

Explanatory Variable	Relative Importance of Attributes													
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1. Total time	1.000	1.000	0.614	0.984	1.000	1.000	1.000	1.000	--	--	0.636	0.648	0.886	0.835
2. Walking time	0.523	0.452	0.614	1.034	0.311	0.338	0.474	0.727	0.706	0.946	1.000	1.000	0.400	0.328
5. Chance of seat	0.554	0.294	--	--	--	--	--	--	0.549	0.611	--	--	--	--
7. Safety	--	--	--	--	--	--	--	--	--	--	0.364	0.636	1.000	1.000
8. Security	0.769	0.756	1.000	1.000	--	--	0.750	0.833	--	--	0.636	0.811	--	--
10. Activity en route	--	--	0.456	0.636	--	--	--	--	--	--	0.705	0.572	--	--
11. Flexibility	--	--	--	--	--	--	0.289	0.397	0.510	0.569	--	--	--	--
13. Total cost	--	--	--	--	--	--	0.289	0.462	--	--	0.955	1.504	0.657	0.671
14. Parking space	--	--	--	--	--	--	--	--	1.000	1.000	0.682	0.683	--	--

a. Definition of station groups is given in the text.

Table 24

DIFFERENCE IN ATTRIBUTE SATISFACTION RATINGS BETWEEN ALTERNATIVE MODES
BART-BUS CHOICE, WORK TRIPS
STRATIFIED BY ORIGIN BART STATION GROUP[a]

Explanatory Variable	Difference in Attribute Satisfaction Ratings[b]						
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Total time	-0.81	-2.53	-0.66	-0.58	-3.14	-0.41	1.70
Walking time	-0.24	-1.13	0.21	-0.10	-0.81	-0.25	0.42
Chance of seat	-2.86	-2.68	-4.27	-2.40	-3.57	-4.63	-1.93
Safety	0.19	-0.17	0.05	0.29	-0.25	-0.06	0.60
Security	0.63	0.41	0.01	0.59	0.26	-0.53	0.70
Activity en route	-0.43	-0.47	-1.28	-0.11	-0.52	-1.33	0.73
Flexibility	-0.39	-1.54	0.80	0.45	-0.97	1.51	1.80
Total cost	-0.08	-1.06	-0.12	-1.30	-1.27	0.20	-1.70
Parking space	0.09	0.19	0.01	0.15	0.08	-1.07	-0.74

a. Definition of station groups is given in the text.
b. BART attribute satisfaction rating minus bus attribute satisfaction rating (positive number indicates BART perceived favorably).

other hand, transbay bus services are frequent and many of them are express services. As a result, bus provides significant total travel time advantages over BART for most travelers. In addition, travelers transferring onto a BART train at one of the Oakland stations are likely to have to stand during the peak periods for their journey across the Bay. This may explain why activity en route appears as an important factor.

Group 3 (Orinda, Rockridge)

Of the 137 travelers in this group, 82 (60%) use BART and 55 (40%) use bus. The factors indicated as important in mode choice are total travel time and walking time. No other factors appear as significant.

Group 4 (Fruitvale, Coliseum, San Leandro, Bay Fair)

A total of 193 travelers in the sample comes from this group; 77 (40%) of these use BART and 116 (60%) use bus. The most important factor in mode choice is total travel time followed by security, walking time, flexibility, and total travel cost. Again, the areas represented by this group are generally well served by AC Transit, including express bus runs to San Francisco. Transbay fares are between 15% to 20% lower than transbay BART fares for these individuals.

Group 5 (Richmond, El Cerrito del Norte, El Cerrito Plaza)

Of the 115 travelers in this group, only 16 (14%) actually use BART and 99 (86%) use bus. Walking time, chance of seat, flexibility, and parking space are estimated to be most important in their choice of travel mode. BART's relatively low share may again reflect the disadvantage BART suffers as a result of the lack of direct transbay service at these stations. The appearance of the chance of seat attribute as important may result from the need to transfer to an already crowded BART train for transbay trips. BART enjoys an advantage in attracting travelers in this group because of the availability of parking space at these stations.

Group 6 (Concord, Pleasant Hill, Walnut Creek, Lafeyette)

Of the 643 travelers in this group, 376 (58%) use BART and 267 (42%) use bus. Walking time, total cost, activity en route, parking space, security, total travel time, and safety are all significant important factors for these people in choosing between BART and bus. The large number of significant attributes reflects the large sample size available for the group.

Most BART travelers from the area use automobile to get to the station, so they usually walk a shorter distance than bus riders at the home end of the trip. On average, bus fares are higher than BART fares for most

of these transbay work trip makers. Parking at these four BART stations is a problem for many of the travelers. All parking spaces at these stations are fully occupied by early in the morning, requiring people to drive to other "downstream" BART stations or to make their trip by bus.

Group 7 (Hayward, South Hayward, Union City, Fremont)

Out of a total of 115 individuals in this group, 81 (70%) actually use BART and 34 (30%) use bus. The attributes considered by this group as important to mode choice are total time, walking time, safety, and total cost. At the time of the transbay survey, only some of this area (Hayward and South Hayward) was served by AC Transit. Total travel time by BART is lower than by bus for most travelers. The cost of using BART, however, is about 25% to 30% higher than for bus. For the areas not served by AC Transit (Union City and Fremont), BART offers substantial savings in both total time and total cost compared to bus services provided by Peerless Stages.

X. BART-AUTOMOBILE CHOICE MODELS: WORK TRIPS STRATIFIED BY BART ACCESS MODE

In this chapter, individuals are classified according to the mode they use to reach an East Bay BART station for an actual or hypothetical transbay work trip on BART. Three access modes are studied: bus, walking, and automobile.

Of the 718 individuals who make a choice between BART and automobile for a transbay trip to work, 59 (8%) use or would use bus to reach their origin BART station; 127 (18%) walk or would walk to their origin BART station; and 532 (74%) drive or would drive to their origin BART station.

Table 25 presents results of model estimation. Two of the three stratified models are slightly better than the aggregate models in terms of goodness of fit (see Table 11, Chapter IV). However, the total number of individuals correctly classified by the three stratified models is the same as that of the aggregate model. Table 26 shows the relative importance of the attributes. The number of attributes appearing in each stratification (with coefficients significant at the 5% level) is largely determined by the sample size.

Bus Access

Of the travelers in this group, 27 (46%) use bus, and 32 (54%) would use bus to get to their origin BART station. Chance of getting a seat and total cost are shown as important. Over 64% of individuals in this group board transbay BART trains (for an actual or hypothetical BART trip) at the central Oakland stations where seats on BART are difficult to find. Approximately 36% of the travelers come from the Fremont and Concord areas where total costs of traveling by BART are substantially lower than by automobile.

Walking Access

Of the 127 people in this sample, 75 (59%) actually walk to their origin BART station, and 52 (41%) would walk if they were to make the trip on BART. An analysis of the data shows that about 80% of people who walk to BART stations are from the Richmond Line and central Oakland areas. Thus, factors considered by the walking access group as important are largely the same as those for the Richmond Line and central Oakland station groups shown in Chapter VIII: total time and safety appear as important to modal choice.

Table 25

RESULTS OF MODEL ESTIMATION
BART-AUTO CHOICE, WORK TRIPS
STRATIFIED BY ACCESS MODE TO BART STATION

	Coefficient Estimates (t-statistic)					
	Bus Access		Walking Access		Auto Access	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1 Total time	--	--	0.084 (6.2)	0.564 (4.7)	0.033 (4.3)	0.174 (4.0)
2 Walking time	--	--	--	--	0.026 (3.3)	0.146 (3.2)
5 Chance of seat	0.072 (2.8)	0.412 (2.3)	--	--	--	--
7 Safety	--	--	0.043 (2.3)	0.327 (2.4)	--	--
8 Security	--	--	--	--	0.028 (2.7)	0.171 (2.7)
10 Activity en route	--	--	--	--	0.015 (2.5)	0.076 (2.3)
11 Flexibility	--	--	--	--	0.046 (6.3)	0.260 (5.6)
13 Total cost	0.071 (3.7)	0.396 (2.9)	0.024 (1.8)	0.120 (1.4)	--	--
Constant	0.554	0.210	0.537	0.274	0.708	1.155
R^2 or likelihood ratio index	0.337	0.289	0.350	0.337	0.260	0.227
F or likelihood ratio statistic	14.2	23.6	22.1	59.4	36.9	167.3
Percent correctly classified	76.3	76.3	77.2	76.6	72.6	71.8

Table 26

INFERRED RELATIVE IMPORTANCE OF ATTRIBUTES
BART-AUTO CHOICE, WORK TRIPS
STRATIFIED BY ACCESS MODE TO BART STATION

	Relative Importance of Attributes					
	Bus Access		Walking Access		Auto Access	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1 Total time	--	--	1.000	1.000	0.717	0.669
2 Walking time	--	--	--	--	0.565	0.562
5 Chance of seat	1.000	1.000	--	--	--	--
7 Safety	--	--	0.512	0.580	--	--
8 Security	--	--	--	--	0.609	0.658
10 Activity en route	--	--	--	--	0.326	0.292
11 Flexibility	--	--	--	--	--	--
13 Total cost	0.986	0.961	0.286	0.213	1.000	1.000

Automobile Access

Of the 532 travelers in this sample, 297 (56%) actually use BART for their transbay mode (and drive to the station) and 235 (44%) drive to San Francisco (and would drive to BART stations if they were to use it). Five attributes are indicated by the model as important to this group's choice of mode: total time, security, activity en route, flexibility, and walking time. Walking times for BART and automobile are likely to be about the same at the origin end of the trip. The only possible source of difference is the egress part of the trip. If automobile users park their automobiles close to their destinations, walking time could differ substantially, especially for individuals working in the Ferry Building/Embarcadero Center area, since the BART Embarcadero Station was not in service at the time of the transbay survey.

XI. BART-BUS CHOICE MODELS: WORK TRIPS STRATIFIED BY BART ACCESS MODE

A total of 1,518 individuals make up the sample of travelers who choose between BART and bus for a transbay work trip. Of these, 281 (18%) ride or would use bus to reach their origin BART stations; 253 (17%) walk or would walk to their origin BART stations; and 984 (64%) drive or would drive an automobile to their origin BART stations. Table 27 shows results of model estimation (including only those coefficients which are significant at the 5% significance level) and Table 28 shows the relative importance of the attributes. In general, the stratified models provide improved goodness of fit relative to the models summarized in Table 13, Chapter V, and slightly increase the percent of individuals correctly classified.

Bus Access

There are 281 individuals in this sample of whom only 63 (22%) actually ride bus to their origin BART station. The other 218 say they would use bus as an access mode to reach their origin BART station if they were to make the trip on BART. For this group, total time, walking time, chance of seat, and security appear in the model as important in choosing between BART and bus. Most (65%) of the individuals in this group are people from the Richmond Line and Oakland who must board a transbay train at one of the central Oakland stations where their chances of getting a seat are small in the peak. Walking time may appear as important because of differences in walking time between the BART station and the trip destination on the one hand, and between the Transbay Bus Terminal and the destination on the other (keeping in mind that the Embarcadero BART station was not in service at the time of the survey). Security may appear as important because many individuals in this group are people from the Richmond Line and central Oakland stations who will typically have to stand in a crowded BART train for their transbay trip.

Walking Access

Of the individuals in this group, 85 (34%) walk to their origin BART station and 168 (66%) would walk to the BART stations if they were to make the trip on BART. For these travelers, total travel time, walking time, safety, and total cost are important considerations in mode choice. Most individuals in this group are from the Richmond Line and central Oakland areas where convenient and relatively fast AC Transit transbay bus services are available. Bus fares are also slightly lower than BART fares for these people. Walking time probably appears as important to these travelers for the same reasons discussed earlier.

Table 27

RESULTS OF MODEL ESTIMATION
BART-BUS CHOICE, WORK TRIPS
STRATIFIED BY ACCESS MODE TO BART STATION

	Coefficient Estimates (t-statistic)					
	Bus Access		Walking Access		Auto Access	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1 Total time	0.049 (5.6)	0.505 (4.7)	0.070 (7.3)	0.625 (4.6)	0.054 (9.2)	0.398 (8.4)
2 Walking time	0.034 (3.4)	0.467 (3.6)	0.048 (4.9)	0.664 (4.4)	0.033 (6.1)	0.260 (6.0)
5 Chance of seat	0.027 (3.1)	0.193 (2.3)	--	--	--	--
7 Safety	--	--	0.026 (2.0)	0.420 (2.3)	0.025 (3.1)	0.252 (3.8)
8 Security	0.048 (4.0)	0.552 (4.0)	--	--	--	--
10 Activity en route	--	--	--	--	0.026 (4.8)	0.180 (4.7)
13 Total cost	--	--	0.043 (3.7)	0.830 (3.8)	0.048 (7.0)	0.440 (7.3)
14 Parking space	--	--	--	--	0.014 (3.0)	0.122 (3.2)
Constant	0.422	-0.436	0.494	-0.142	0.634	0.882
R^2 or likelihood ratio index	0.386	0.579	0.533	0.646	0.405	0.409
F or likelihood ratio statistic	43.4	225.6	70.8	226.5	110.7	557.6
Percent correctly classified	85.8	86.5	90.1	90.9	82.1	82.3

Table 28

INFERRED RELATIVE IMPORTANCE OF ATTRIBUTES
BART-BUS CHOICE, WORK TRIPS
STRATIFIED BY ACCESS MODE TO BART STATION

	Relative Importance of Attributes					
	Bus Access		Walking Access		Auto Access	
Explanatory Variable	Linear Model	Logit Model	Linear Model	Logit Model	Linear Model	Logit Model
1 Total time	1.000	1.000	1.000	1.000	1.000	1.000
2 Walking time	0.694	0.925	0.686	1.062	0.611	0.653
5 Chance of seat	0.551	0.382	--	--	--	--
7 Safety	--	--	0.371	0.672	0.463	0.633
8 Security	0.980	1.093	--	--	--	--
10 Activity en route	--	--	--	--	0.481	0.452
13 Total cost	--	--	0.614	1.328	0.907	1.106
14 Parking space	--	--	--	--	0.259	0.307

Automobile Access

Out of the 984 individuals in this sample, 569 (58%) actually use BART and 415 (42%) use buses. Most (67%) of the travelers in this group are from the Concord Line, with a further 19% from the Fremont Line. As a consequence, the attributes that are considered important by these travelers are similar to those for the Concord Line and Fremont Line groups, as presented in Chapter IX. These attributes are: total time, walking time, safety, activity en route, total cost, and parking space.

XII. RELATIONSHIPS BETWEEN SATISFACTION RATINGS AND ATTRIBUTE VALUES

The models developed in the preceding chapters estimate the relative importance of modal attributes in mode choice decisions. These models may be used to indicate the likely sensitivity of BART patronage to changes in satisfaction with BART attributes. This may be done by recomputing the probability of mode choice for each individual as a function of a new set of relative satisfaction ratings, aggregating the BART choice probabilities over the sample, and comparing this aggregate with the original set of choice probabilities. But to apply these models in analyzing the ridership changes likely to result from specific BART improvements, we need to have estimates of the new satisfaction ratings associated with the improvements. These may be obtained from a "projective" survey in which respondents are asked to give semantic-scaled ratings of how satisfied they would be with a hypothetical set of new attribute values. However, aside from the time and expense required to conduct such a survey, there are inherent uncertainties about the reliability of such projective responses. An alternative approach is to estimate functional relationships which can be used to predict the attribute satisfaction rating likely to be associated with a new attribute value. In this chapter, we will attempt to develop such functional relationships.

Quantification of Modal Attributes

We will focus our attention on the attributes that have been found in earlier chapters to be significant in work travel mode choices. We will also only be concerned with attributes of the BART System that may reasonably be expected to change in the short run. Finally, we will obviously also be concerned only with those attributes for which data are available for both attribute values and their associated attribute satisfaction ratings. Based on these criteria, we selected the following four attributes and physical measures used to quantify them:

BART Attribute	Physical Measurement
Total door-to-door travel time	Total travel time in minutes
Time spent walking	Walking time in minutes
Chance of seat	Load factor at boarding station
Total door-to-door trip cost	Total travel costs in dollars

Data on total travel time (in minutes) and total travel cost (in dollars) can be obtained directly from the transbay travel survey. However, the survey questionnaire did not request the respondent to provide his total walking time during the trip. Consequently, walking times were estimated using the following procedure: If the traveler

walks to the BART station, then the access time which is indicated on the questionnaire is the access walk time. If the access mode is auto, then access walk time is assumed to be two minutes. If the traveler uses bus to get to the BART station, the access walk time is assumed to be six minutes (the average access time for bus users in the survey). A similar procedure was used to determine egress walk times. The sum of access and egress walk times then constitutes the estimated total time spent walking during the trip. Since bus and auto walk times are set at constant values, they do not reflect the actual variations among travelers. Unfortunately, the detailed information on trip origins and destinations necessary to estimate these variations is not available.

Load factor at boarding station is estimated as follows: First, peak-period link flows (between adjacent stations) are computed from BARTD's Data Acquisition System (DAS) summaries of typical daily ridership. A relative flow factor is then computed for each link using the flow between Oakland Center (12th Street) and Oakland West Stations as the base for links on the Richmond and Concord Lines; and the flow between Lake Merritt and Oakland West Stations as the base for links on the Fremont Line. These base flows are selected because BARTD regularly observes peak-hour train load factors at the Oakland West Station for the Fremont-Daly City and Concord-Daly City trains. Finally, load factor at boarding station is determined by multiplying the relative flow factor on the immediate downstream link by the appropriate load factor as measured at the Oakland West BART Station.

The other important attribute which might be analyzed is flexibility (to travel when you want to) using service frequency (or average headway) as the appropriate physical measure. However, in practice, it becomes a futile exercise to attempt to relate satisfaction ratings and attribute values for this attribute because there is very little variation in published headways on the System.

Relationship between Satisfaction Rating and Attribute Value

According to the choice model developed in Chapter I, if k (the number of intervals in the semantic differential scale) remains the same for all attribute satisfaction ratings, and M_i is a constant for any given attribute i, Equation (2) says that one can determine the satisfaction rating $Q_i(X_{ij})$ for attribute i with value X_{ij} from

$$Q_{ij} = kU_{ij}/M_i$$

where the simplified notation Q_{ij} represents $Q_i(X_{ij})$, and U_{ij} represents $U_i(X_{ij})$.

U_{ij} is specified to be a monotonic function of X_{ij}, say g. One can assume different functional forms of g and calibrate the relationship, which, for the remainder of this report, will be called the Q/X relationship. Three functional forms of g are postulated in this study:

(1) a linear form,

$$Q_{ij} = \alpha + \beta X_{ij} \tag{9}$$

(2) an exponential form,

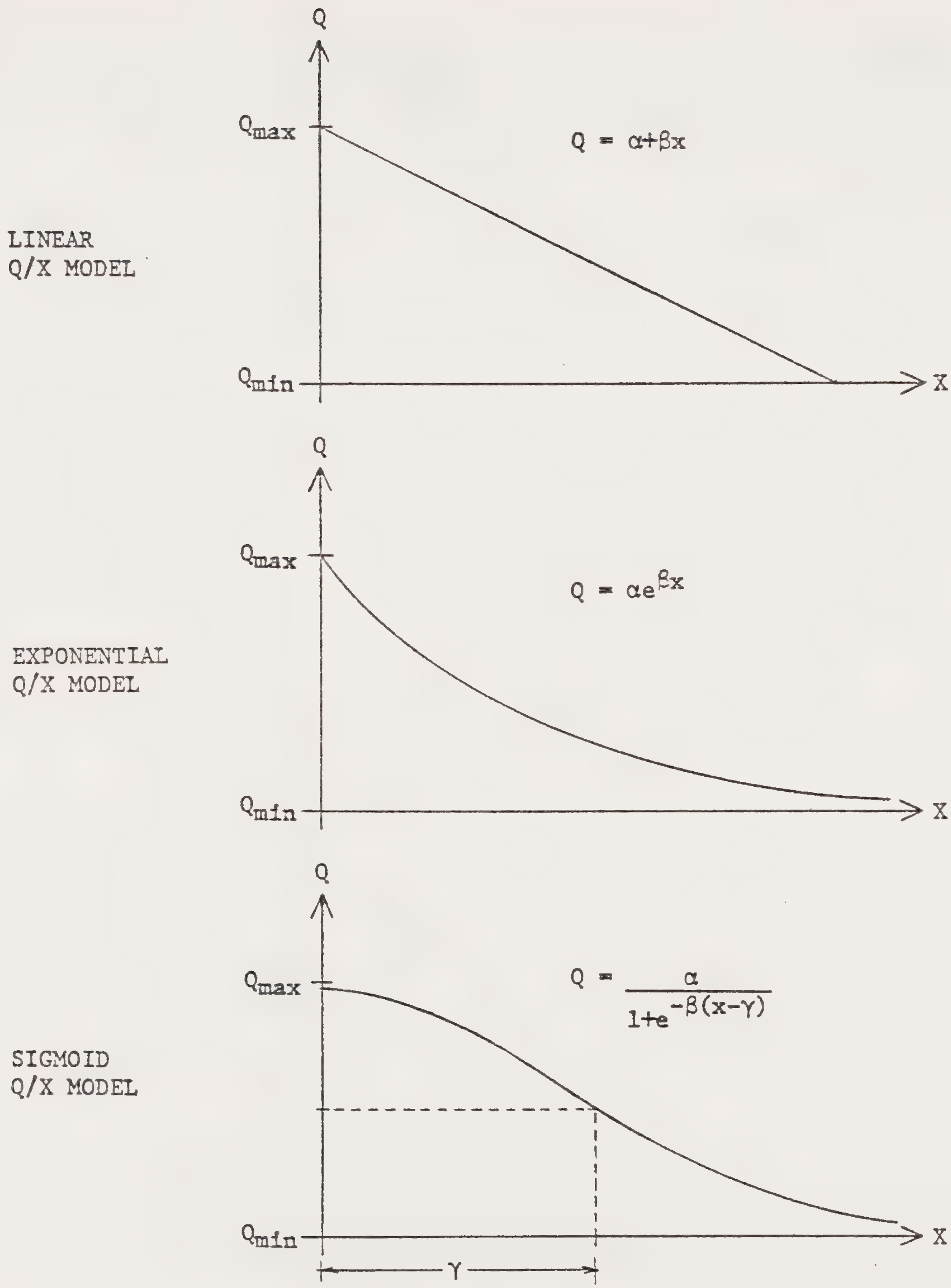
$$Q_{ij} = \alpha e^{\beta X_{ij}} \tag{10}$$

(3) a sigmoidal form,

$$Q_{ij} = \frac{\alpha}{\left[1 + e^{-\beta(X_{ij} - \gamma)}\right]} \tag{11}$$

The estimates of the parameters α, β, and γ are denoted by the coefficients a, b, and c, respectively, in the rest of the discussion. The alternative Q/X functional forms are illustrated graphically in Figure 1. Their general shapes are defined by the nature of the attributes being analyzed: As total time, walking time, chance of seat (as measured by load factor), and total cost increase, satisfaction with their attribute values decreases. For the relationship to be valid and meaningful, the coefficient a should be equal to Q_{max}, the maximum satisfaction rating, and the coefficient b should be negative for all three forms shown in Figure 1. The only difference between the three functional forms is in their rate of change of satisfaction rating with respect to change in attribute value. The exponential form (or more strictly, negative exponential form) states that the rate of change is ever slower and approaches Q_{min} asymptotically. The sigmoidal (s-shaped) form is perhaps more appealing intuitively. With this relationship the rate of change in satisfaction is much slower at the extreme ends on the attribute value scale indicating that there are "threshold" values beyond which there is little change in traveler attitude. Note that the parameter γ is used here to "shift" the sigmoidal curve so that the curve is symmetric about the line $X = \gamma$. In other words, the value of Q is equal to 0.5 Q_{max} when X equals γ. This ensures that Q is very close to Q_{max} when X = 0.

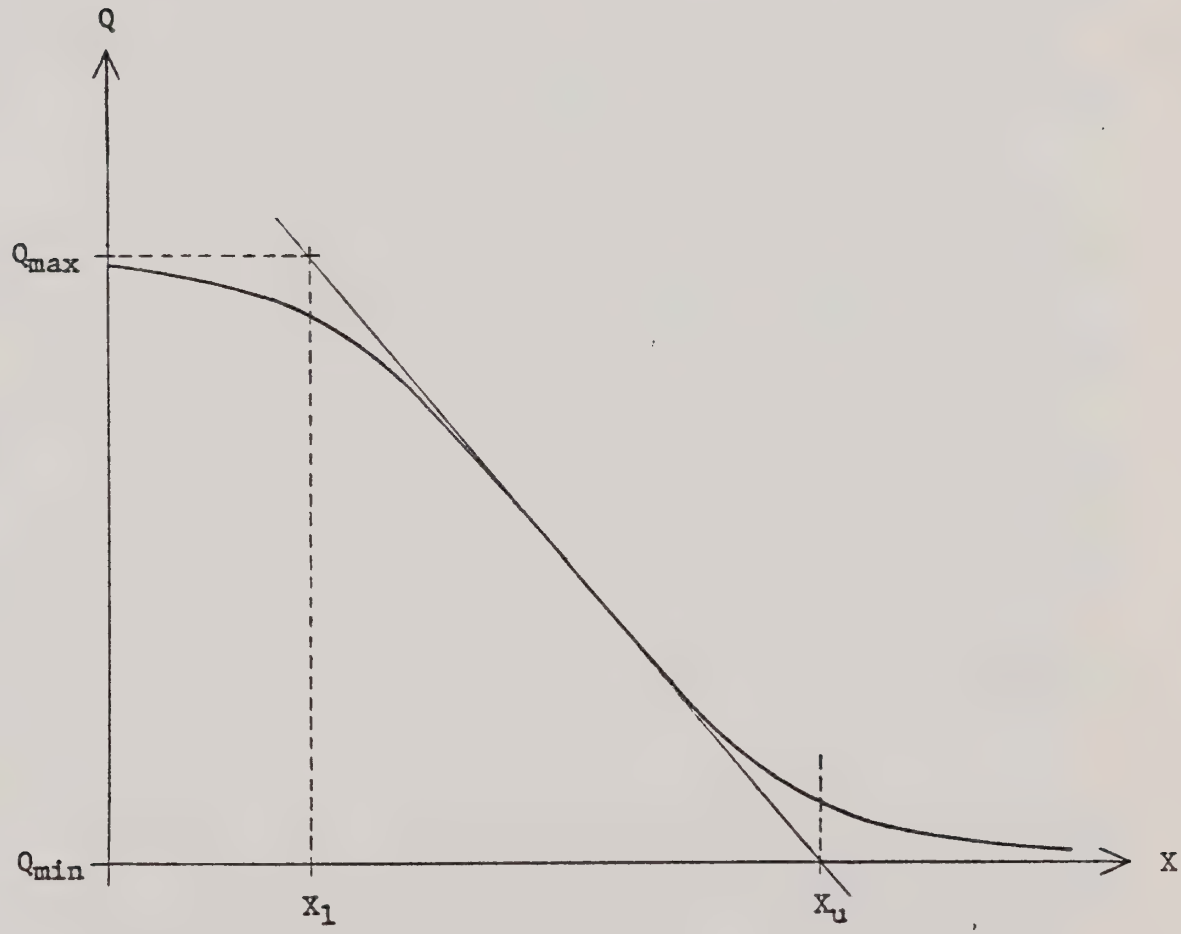
The linear form is obviously the simplest, with a constant rate of change. This can lead to unrealistic (out of range) estimates for the extreme cases. Nevertheless, it provides a simple and useful approximation to the sigmoidal form as illustrated in Figure 2. In applying the



Q = Satisfaction rating
X = Attribute value
Q_{max} = Maximum satisfaction rating
Q_{min} = Minimum satisfaction rating
α, β, γ = Parameters

Figure 1

POSTULATED RELATIONSHIPS BETWEEN SATISFACTION RATING AND ATTRIBUTE VALUE



Q = Satisfaction rating
X = Attribute value
Q_{max} = Maximum satisfaction rating
Q_{min} = Minimum satisfaction rating

Figure 2

LINEAR APPROXIMATION OF SIGMOIDAL RELATIONSHIP
BETWEEN SATISFACTION RATING AND ATTRIBUTE VALUE

Q/X relationship in analyzing ridership changes, it is changes in attribute values bounded by X_l (lower bound) and X_u (upper bound) that are of interest, since any changes outside of these bounds will not significantly affect satisfaction. In other words, X_l is the value of the attribute that gives nearly full satisfaction to the traveler. Any additional improvement in this attribute will not significantly increase satisfaction. Similarly, X_u represents the attribute value corresponding to a satisfaction level so low that any additional deterioration will not lower satisfaction by a significant amount. In most cases, the portion of the sigmoid curve between these two limits can be approximated closely by a straight line. The validity of this assumption is examined later.

Estimation of the Q/X Relationship

An ideal data base for estimating the Q/X relationship would be longitudinal travel data which reflect changes in traveler attitude due to various system attribute changes. In real situations, such data are rarely available. In our case the three functional forms shown in Equations (9), (10), and (11) are estimated on the same transbay survey data used to estimate the work travel choice models presented in Chapters VIII and IX, with the hope that there is sufficient systemwide variation in attribute values for the estimated relationships to be statistically significant. The data consist of the BART-automobile work trip choice sample and BART-bus work trip choice sample, each stratified by BART station group. Least-squares regression was used to estimate both linear and nonlinear (exponential and sigmoidal) relationships. Note that, for simplicity, the value of individual satisfaction ratings is reduced by one. That is, satisfaction ratings take on integer values 0 through 6, rather than 1 through 7. For nonlinear regression, the coefficient a is constrained to equal 6, the maximum satisfaction rating.

For the linear Q/X relationship, the closeness of the estimate a to 6 gives an indication of the validity of the assumed relationship. Because of the peculiarities of the data set, and the nonlinear functional forms of the exponential and sigmoidal relationships, measures of statistical significance of the regressions are difficult to compute. To assist both in judging the significance of the nonlinear regressions and in comparing them with their linear counterpart, three measures (common to both linear and nonlinear regressions) are computed for each regression and shown in the summary tables. These are (1) F-test for lack of fit, (2) proportion of variation explained by regression, and (3) proportion fitted plus or minus one (± 1). These three are further explained below.

F-Test for Lack of Fit. In a correctly specified regression model, whether linear or nonlinear, the residual mean square (i.e., the mean square due to residual variation about the regression line) has an

expected value equal to the error variance (i.e., the true random variation present in the observations). Thus, the adequacy of a regression equation may be tested by comparing the residual mean square with the error variance. If the residual mean square is significantly greater than the error variance (in other words, if significant bias error is present) there is considered to be "lack of fit."

Where repeat (two or more) measurements of the dependent variable have been made at the same value of the independent variable, the repeat measurements may be used to obtain an estimate of the error variance. This estimate is said to represent "pure error" because, if the value of the independent variable is identical for two observations (i.e., the dependent variable), only random variation can influence the results and provide differences between them. Our data set can be used to provide such an estimate of "pure" error variance since several attribute (X) values are generally associated with a given satisfaction (Q) rating.

The significance of the difference between the residual mean square and the "pure error" mean square estimate of error variance may be tested using the F-statistic. Mathematically, if we have n_i repeat observations of satisfaction ratings Q_{ij} ($j = 1, \ldots, n_i$) at attribute level X_i ($i = 1, \ldots, k$), and if $\overline{Q}_i$ denotes the average satisfaction rating for attribute i, then the pure error mean square, MSP, is given by:

$$MSP = \sum_{ij}\sum(Q_{ij} - \overline{Q}_i)^2 \Big/ (\sum_i n_i - k) \qquad (12)$$

A quantity MSL (lack of fit mean square) may be determined by subtracting the pure error sum of squares from the residual sum of squares and dividing by the appropriate degrees of freedom.

The ratio F = MSL/MSP may then be compared with the 100 $(1 - \alpha)$% point of an F distribution with the appropriate degrees of freedom. For each Q/X regression model summarized in the tables of this chapter, the F-ratio to test for lack of fit (as described above) is given, along with the appropriate test statistic.

<u>Proportion of Variation Explained by Regression</u>. This is computed by taking the ratio of the sum of squares due to regression to the sum of squares about the mean. In linear regression, the proportion of total variation about the mean explained by the regression is indicated by the square of the correlation coefficient (the R^2 statistic). In our nonlinear regressions, because the parameter is constrained to equal 6, the sum of squares due to the regression may be negative (i.e., the residual sum of squares may be greater than the sum of squares about the

sample mean). Furthermore, the F-statistic cannot be used to obtain conclusions about the significance of the nonlinear regressions at any stated level because the estimates of sample variance upon which the statistic is based are in general biased.

Proportion Fitted $\pm$1. The fitted Q/X relationships are all continuous functions, while the observations being fitted (the satisfaction ratings) can take on only integer values. This being the case, the residual mean square does not necessarily give an appropriate indication of the goodness-of-fit. As a supplemental measure of the fit of the data to the regression curve, the proportion of observations having values within plus or minus one of the predicted value was computed and is given in the summary tables as "proportion fitted $\pm$1."

BART-Automobile Choice

Tables 29, 30, and 31 show results of the estimated linear, exponential, and sigmoidal Q/X relationships, respectively, for the BART-automobile choice sample.

For the linear relationships estimated for the seven station groups (see Table 29), all the b coefficients are significant and have the correct (i.e., negative) sign. The value of a is also close to 6, the maximum satisfaction rating, except for Station Group 7. This is probably due to the fact that individuals in this group are all from stations on the southern half of the Fremont Line (Hayward to Fremont). One might hypothesize that, because these people are far from their destinations, they accept that even under ideal conditions it would take them a certain minimum time to reach their destinations. This implies that they will attain full satisfaction (with regard to travel time) at an attribute value much larger than zero minutes. If we assume that the average traveler in this group regards 25 minutes as the minimum possible time to travel to his San Francisco destination, then the estimated value of a is reduced from 8.48 to 6.81. The values of the "proportion of variation explained" (or R^2), though low, are all significant at the 5% level.

An examination of the F-test for lack of fit (given in Table 29) reveals that most of the estimated relationships are quite adequate save for the walking time attribute for Station Groups 3 and 6. The proportion of fitted values within $\pm$1 of the observed values also indicate reasonable fits for most attributes.

The lack of fit in the walking time attribute is probably largely accounted for by the assumptions used in estimating the time spent walking by individual travelers. Specifically, the constant values of walking time assigned to travelers using automobile or bus as their access/egress mode give rise to limited overall variation within the sample data. This lack of variation could only be overcome by constructing walking times on an individual basis. This is not attempted

Table 29

SUMMARY OF ESTIMATED LINEAR SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-AUTOMOBILE CHOICE, WORK TRIPS

Coefficient or Statistic	BART Station Group									
	Group 1	Group 2	Group 3		Group 4	Group 5	Group 6			Group 7
	Total Time	Total Time	Total Time	Walking Time	Total Time	Total Time	Total Time	Walking Time	Total Cost	Total Time
a	6.22	5.35	6.22	5.41	5.47	4.58	6.34	5.19	4.65	8.48
b	-0.054	-0.048	-0.057	-0.131	-0.034	-0.041	-0.047	-0.080	-0.400	-0.067
(t-statistic)[a]	(6.6)	(4.9)	(5.2)	(4.2)	(3.2)	(2.9)	(5.8)	(3.9)	(2.5)	(5.6)
Proportion of variation explained	0.282	0.259	0.183	0.126	0.112	0.191	0.137	0.069	0.030	0.292
F (lack of fit)[b]	0.99	1.04	0.91	1.96[c]	0.81	0.91	0.58	2.62[c]	0.90	1.35
Critical $F_{0.95}$	1.63	1.78	1.59	1.75	1.71	2.22	1.43	1.61	1.39	1.73
Proportion[d] Fitted $\pm$ 1	0.667	0.634	0.650	0.512	0.590	0.632	0.543	0.695	0.552	0.671
Sample size	114	71	123		83	38	210			79

Linear form: $Q = a+bX$

a. t-statistic to test null hypothesis b = 0.
b. The ratio of mean square for lack of fit to mean square for pure error.
c. Significant lack of fit.
d. Explanation given in text.

Table 30

SUMMARY OF ESTIMATED EXPONENTIAL SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-AUTOMOBILE CHOICE, WORK TRIPS

	BART Station Group									
	Group 1	Group 2	Group 3		Group 4	Group 5	Group 6			Group 7
Coefficient or Statistic	Total Time	Total Time	Total Time	Walking Time	Total Time	Total Time	Total Time	Walking Time	Total Cost	Total Time
b	-0.0109	-0.0160	-0.0119	-0.0414	-0.0095	-0.0189	-0.0095	-0.0338	-0.2358	-0.0064
Proportion of variation explained	0.259	0.234	0.166	0.157	0.102	0.224	0.118	0.092	-4.846	0.172
F (lack of fit)[a]	1.08	1.09	0.96	1.55	0.81	0.78	0.68	2.17[b]	0.99	1.87[b]
Critical $F_{0.95}$	1.62	1.77	1.59	1.74	1.71	2.21	1.40	1.59	1.38	1.72
Proportion[c] Fitted $\pm$ 1	0.640	0.577	0.634	0.512	0.614	0.632	0.505	0.690	0.110	0.532
Sample size	114	71	123		83	38		210		79

Exponential form: $Q = 6e^{bX}$

a. The ratio of mean square for lack of fit to mean square for pure error.
b. Significant lack of fit.
c. Explanation given in text.

Table 31

SUMMARY OF ESTIMATED SIGMOIDAL SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-AUTOMOBILE CHOICE, WORK TRIPS

Coefficient or Statistic	BART Station Group: Group 1	Group 2	Group 3		Group 4	Group 5	Group 6			Group 7
	Total Time	Total Time	Total Time	Walking Time	Total Time	Total Time	Total Time	Walking Time	Total Time	Total Time
b	-0.0493	-0.0494	-0.0454	-0.1239	-0.0295	-0.0645	-0.0353	-0.1786	-0.5873	-0.6018
c	53.5	56.0	53.5	12.7	61.0	51.0	68.5	13.6	2.22	75.0
Proportion of variation explained	0.266	0.250	0.176	0.055	0.073	0.217	0.133	-0.032	-4.849	0.242
F (lack of fit)[a]	1.04	1.03	0.91	2.03[b]	0.91	0.80	0.59	3.82[b]	1.35	1.53
Critical $F_{0.95}$	1.62	1.77	1.59	1.74	1.71	2.21	1.40	1.59	1.38	1.72
Proportion[c] Fitted $\pm$ 1	0.701	0.620	0.642	0.431	0.578	0.632	0.557	0.671	0.110	0.683
Sample size	114	71	123		83	38		210		79

Sigmoidal form: $Q = 6/(1+e^{-b(X-c)})$

a. The ratio of mean square for lack of fit to mean square for pure error.
b. Significant lack of fit.
c. Explanation given in text.

in this study. Walking time is considered significantly important in the choice between BART and automobile in only two of the seven station groups (see Table 20, Chapter VIII), and even for these two groups walking time is the least important consideration among the significant factors. Furthermore, the average satisfaction ratings for walking time for these two station groups (3 and 6) are 4.41 and 4.19, respectively, (a rating of 6 indicating maximum satisfaction) with an average walking time of around nine minutes for both groups. This suggests that the effects of any improvement on BART trip walking time may be minor, at least for transbay work trip makers choosing between BART and automobile.

As shown in Table 30, for the exponential relationships fitted on the same data, the coefficients b again all have the correct sign. The lack-of-fit F-test and "proportion fitted ± 1" values are similar to those for the linear relationship except for the total cost attribute in the case of Station Group 6. Similar observations can be made on the estimated sigmoidal relationship summarized in Table 31.

In general, then, there seems to be little to choose between the three functional forms. For computational simplicity, the linear form will be used in this study for analysis of ridership changes given in Chapter XIII.

BART-Bus Choice

The same three functional Q/X relationships were also estimated for workers with a choice of travel mode between BART and bus. Results of this estimation are shown in Tables 32, 33, and 34 for the linear, exponential, and sigmoidal forms, respectively.

For the linear case, the values of the coefficient b are all significant and have the correct sign. The only exceptions are the total cost attribute for Station Group 7 and the chance of seat attribute for Station Group 1. The R^2 values are all significant at the 5% level except for the chance of seat attribute for Station Group 1. As indicated by the statistics given in Table 32, the estimated relationship between satisfaction rating and the total cost attribute is not adequate. In fact, none of the three postulated functional Q/X relationships are convincing for the cost attribute. In this exercise, we assume the relationship estimated for Station Group 4, the northern half of the Fremont Line, also applies to Group 7, the southern half of the same line.

The problem with the total cost Q/X relationship stems mainly from the data for total travel cost (on BART) which reflect BART's fixed fare structure. The resulting lack of variation in travel cost impacts our estimation of the Q/X relationships. This is true in the cases of Station Groups 4 and 6 (as well as for Group 7); the R^2 values for Groups 4 and 6 are very low (even though still significant). The lack-of-variation

problem also exists in the data for chance of seat (load factor) and, to a lesser degree, walking time. The only attribute which has a large within-sample variation in attribute values is total travel time, and not surprisingly, its Q/X relationships are more reliable than those for other attributes.

Table 32 shows that the a values are generally not far from the value 6, and the F-test for lack of fit indicates that most of the estimated relationships are apparently adequate. There is a problem with the walking time attribute for Station Group 6, probably for the same reasons discussed earlier for the BART-automobile choice samples. In any case, the present average satisfaction rating for walking time is about 4.12 (compared to a maximum rating of 6), with an average walking time of about ten minutes, so there is probably limited scope for improvement to this attribute for the BART trip. (It may be sufficient to use as an approximation the relationship estimated for Station Group 3. Trips from this group are similar in characteristic to Station Group 6, with an average satisfaction rating of 4.37 and a ten-minute average walking time.) The proportion of fitted values within ± 1 of the observed values also indicates reasonable fits in most cases. The relatively poor fit for chance of seat is probably due to the limited variation in load factor.

As shown in Table 33, the exponential relationships also have correct signs for the parameter b, and provide reasonable fits to the data studied, albeit the goodness-of-fit (as measured by the proportion fitted ± 1 and the F-ratio) is not quite as good as the linear form in some cases, particularly for the total cost attribute. Similar observation can be made on the sigmoidal relationships (Table 34), except that all but two of the estimated Q/X relationships for the walking time attribute are inadequate.

Comparison of the Q/X results among the three alternative forms suggests that, of the three, the linear relationship provides the best overall fit. Accordingly, the linear form is used in the analysis of BART ridership changes summarized in Chapter XIII. However, it should be emphasized that the results presented in this chapter in no way demonstrate that the estimated Q/X equations are the only or the "best" possible form for the relationships between satisfaction ratings and attribute values, nor are the Q/X relationships estimated for the attributes considered in this chapter necessarily valid for other modal attributes.

Table 32

SUMMARY OF ESTIMATED LINEAR SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-BUS CHOICE, WORK TRIPS

	BART Station Group									
	Group 1			Group 2		Group 3		Group 4		
Coefficient or Statistic	Total Time	Walking Time	Chance of Seat	Total Time	Walking Time	Total Time	Walking Time	Total Time	Walking Time	Total Cost
a	5.62	5.26	4.06	4.58	5.36	6.70	5.90	7.06	5.67	4.33
b	-0.046	-0.065	-0.905	-0.042	-0.108	-0.063	-0.153	-0.062	-0.108	-1.000
(t-statistic)[a]	(4.5)	(4.1)	(1.5)	(5.4)	(5.2)	(6.8)	(6.7)	(8.5)	(6.1)	(3.0)
Proportion of variation explained	0.117	0.098	0.013	0.157	0.150	0.256	0.248	0.276	0.163	0.045
F (lack of fit)[b]	1.45	1.78[c]	1.26	1.02	1.14	1.07	1.44	0.66	1.07	1.45
Critical $F_{0.95}$	1.54	1.55	1.55	1.54	1.59	1.59	1.66	1.44	1.53	1.46
Proportion[d] Fitted $\pm$ 1	0.519	0.658	0.361	0.688	0.599	0.664	0.679	0.642	0.720	0.560
Sample size		158		157		137			193	

Table 32 (cont.)

Coefficient or Statistic	BART Station Group							
	Group 5		Group 6			Group 7		
	Total Time	Walking Time	Total Time	Walking Time	Total Cost	Total Time	Walking Time	Total Cost
a	3.94	5.74	7.30	5.64	5.16	6.33	5.94	2.54
b	-0.034	-0.139	-0.061	-0.154	-1.000	-0.031	-0.126	0.100
(t-statistic)[a]	(3.9)	(6.5)	(11.3)	(12.2)	(6.7)	(2.1)	(4.4)	(0.2)
Proportion of variation explained	0.119	0.271	0.166	0.189	0.066	0.036	0.145	0.00
F (lack of fit)[b]	0.98	1.27	0.48	2.63[c]	1.24	1.15	1.51	0.88
Critical $F_{0.95}$	1.69	1.68	1.37	1.51	1.32	1.64	1.78	1.63
Proportion[d] Fitted $\pm$ 1	0.678	0.652	0.655	0.683	0.614	0.600	0.722	0.539
Sample size		115		643			115	

Linear form: $Q = a+bX$

a. t-statistic to test null hypothesis $b = 0$.
b. The ratio of mean square for lack of fit to mean square for pure error.
c. Significant lack of fit.
d. Explanation given in text.

Table 33

SUMMARY OF ESTIMATED EXPONENTIAL SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-BUS CHOICE, WORK TRIPS

Coefficient or Statistic	BART Station Group									
	Group 1			Group 2		Group 3		Group 4		
	Total Time	Walking Time	Chance of Seat	Total Time	Walking Time	Total Time	Walking Time	Total Time	Walking Time	Total Cost
b	-0.0121	-0.0239	-0.5166	-0.0184	-0.0329	-0.0113	-0.0355	-0.0095	-0.0277	-0.6008
Proportion of variation explained	0.117	0.112	0.003	0.162	0.151	0.202	0.250	0.209	0.170	-3.133
F (lack of fit)[a]	1.40	1.62	1.28	0.96	1.08	1.38	1.35	1.13	0.96	1.54
Critical $F_{0.95}$	1.54	1.55	1.54	1.53	1.58	1.58	1.64	1.44	1.53	1.45
Proportion[c] Fitted $\pm$ 1	0.500	0.684	0.361	0.682	0.592	0.613	0.664	0.580	0.720	0.192
Sample size		158		157		137			193	

Table 33 (cont.)

Coefficient or Statistic	BART Station Group							
	Group 5		Group 6			Group 7		
	Total Time	Walking Time	Total Time	Walking Time	Total Cost	Total Time	Walking Time	Total Cost
b	-0.0195	-0.0344	-0.0092	-0.0409	-0.3467	-0.0050	-0.0265	-0.5678
Proportion of variation explained	0.129	0.242	0.122	0.200	-4.368	0.031	0.155	-2.080
F (lack of fit)[a]	0.87	1.42	1.17	2.18[b]	1.20	1.13	1.33	1.17
Critical $F_{0.95}$	1.68	1.67	1.37	1.50	1.32	1.63	1.77	1.62
Proportion[c] Fitted $\pm$ 1	0.678	0.643	0.619	0.680	0.132	0.583	0.722	0.296
Sample size	115		643			115		

Exponential form: $Q = 6e^{bX}$

a. The ratio of mean square for lack of fit to mean square for pure error.
b. Significant lack of fit.
c. Explanation given in text.

Table 34

SUMMARY OF ESTIMATED SIGMOIDAL SATISFACTION RATING/ATTRIBUTE VALUE RELATIONSHIP
BART-BUS CHOICE, WORK TRIPS

Coefficient or Statistic	BART Station Group									
	Group 1			Group 2		Group 3		Group 4		
	Total Time	Walking Time	Chance of Seat	Total Time	Walking Time	Total Time	Walking Time	Total Time	Walking Time	Total Cost
b	-0.0352	-0.1061	-0.8632	-0.0575	-0.1044	-0.0550	-0.1686	-0.0523	-0.1487	-0.7509
c	52.5	19.8	1.6	55.0	17.2	56.0	14.5	61.0	17.0	1.2
Proportion of variation explained	0.105	-0.058	-0.016	0.063	0.096	0.264	0.184	0.262	0.077	-3.133
F (lack of fit)[a]	1.48	2.78[b]	1.38	1.53	1.50	0.99	1.93	0.75	1.84[b]	1.43
Critical $F_{0.95}$	1.54	1.55	1.54	1.53	1.58	1.58	1.64	1.44	1.53	1.45
Proportion[c] Fitted ± 1	0.532	0.639	0.335	0.675	0.567	0.672	0.672	0.663	0.710	0.192
Sample size		158		157		137			193	

Table 34 (cont.)

Coefficient or Statistic	BART Station Group: Group 5 Total Time	Group 5 Walking Time	Group 6 Total Time	Group 6 Walking Time	Group 6 Total Cost	Group 7 Total Time	Group 7 Walking Time	Group 7 Total Cost
b	-0.0703	-0.1328	-0.0459	-0.1807	-1.0204	-0.0713	-0.1972	-0.1142
c	56.0	16.8	68.0	13.3	1.7	72.0	15.0	1.4
Proportion of variation explained	0.003	0.246	0.158	0.164	-4.368	-0.153	-0.043	-2.080
F (lack of fit)[a]	1.61	1.39	0.59	3.34[b]	1.78[b]	1.96[b]	3.07[b]	0.99
Critical $F_{0.95}$	1.68	1.67	1.37	1.50	1.32	1.63	1.77	1.62
Proportion[c] Fitted $\pm$ 1	0.643	0.670	0.638	0.659	0.132	0.583	0.678	0.296
Sample size	115		643			115		

Sigmoidal form: $Q = 6/(1+e^{-b(X-c)})$

a. The ratio of mean square for lack of fit to mean square for pure error.
b. Significant lack of fit.
c. Explanation given in text.

XIII. SENSITIVITY OF TRANSBAY BART RIDERSHIP TO IMPROVEMENT IN BART ATTRIBUTES

In this chapter, the likely sensitivity of BART ridership to improvements in BART attributes is studied using the choice models and relationships between satisfaction rating and attribute value (Q/X relationships) estimated in earlier chapters. The analysis focuses on transbay work trips with travelers in the sample cross-classified by the two best mode choices available to them (BART-auto and BART-bus) and by origin BART station groups (as defined in Chapter VIII). The analysis investigates only those attributes which were found to be significant in traveler mode choice decisions (see Chapters VIII and IX), and for which Q/X relationships were estimated (see Chapter XII). They are: total door-to-door travel time, time spent walking, chance of seat, and total travel cost. These are also the principal attributes over which BART management can exercise some influence to change ridership on the existing System.

Computation of BART Ridership Sensitivity

The linear probability mode choice model was chosen from among the work trip mode choice models analyzed in Chapters VIII and IX. This is because they are simple and straightforward to use, and provide attribute importance estimates similar to the more complex logit models. They also have the advantage over the logit models that no adjustments to the choice probability estimates are necessary. (As discussed in Chapter I, an adjustment is necessary in the case of the choice-based logit model to account for statistical inconsistency in the constant term.) The simple linear form of Q/X relationship between satisfaction rating and attribute value was also selected from the alternative forms analyzed in Chapter XII.

For each mode choice/station group sample, the sensitivity of BART ridership to a change in the value of a BART attribute is computed as follows:

1. The change in satisfaction rating associated with a postulated change in attribute value is estimated using the applicable Q/X relationship (see Tables 29 and 32, Chapter XII).

2. The change in the probability of choosing BART (over the auto or bus alternative) is computed as a function of the change in attribute satisfaction rating using the applicable mode choice model coefficient (see Table 19, Chapter VIII; and Table 22, Chapter IX).

3. The change in mode choice probability is applied to an estimate of the total population confronting the BART-auto or BART-bus mode choice to give an estimate of the likely change in the total number of people riding BART.

BART-Automobile Choice

Figure 3 shows the sensitivity of BART choice probability to hypothetical percentage improvements in total travel time, walking time, and total travel cost. The chance-of-seat attribute was not found to be important in the BART-automobile mode choice decision (see Chapter VIII). Table 35 details the computations underlying Figure 3 for a postulated 25% decrease in the attribute values. For improvements in total travel time, Table 35 suggests that a 25% decrease in travel time would result in an increase in the probability of a traveler choosing BART ranging from 0.0242 for Station Group 4 (northern half of the Fremont Line) to 0.0589 for Station Group 5 (Richmond-El Cerrito area). For the entire BART System, a 25% across-the-board reduction in travel time (equivalent to an average travel time reduction of 15 minutes for people currently making BART-auto choices) would result in an increase in BART choice probability of about 0.0386 for the travelers choosing between BART and automobile. This increase in choice probability corresponds to an overall increase in BART ridership of 5% (resulting from auto-to-BART diversion only).

As summarized in Table 35, a 25% improvement in walking time would increase BART choice probability by 0.012 and 0.0075 for Station Groups 3 and 6, respectively, and by about 0.0036 overall. A 25% reduction is equivalent to an average decrease in walking time of 2 minutes. The estimated resulting increase in BART ridership is under 1% overall. If total travel costs using BART were reduced by 25% (equivalent to an average $0.38 reduction) there would be an increase of about 0.0014 in BART choice probability, again equivalent to an overall increase of less than 1% in BART ridership.

BART-Bus Choice

Figure 4 illustrates the sensitivity of BART choice probability to percentage improvements in total travel time, walking time, chance of seat, and total travel cost for BART-bus choices. Table 36 details the computations for a postulated 25% change in each of these attributes. The figure and table show that a given percentage reduction in total travel time increases the probability of BART choice by much more than the same percentage improvement in the other three attributes. However, there is also a large variation among the station groups. A postulated 25% reduction in travel time is estimated to increase the BART choice probability from between 0.0242 (for Station Group 2) to 0.0875 (for Station Group 3). Overall, a 25% reduction in total BART travel time

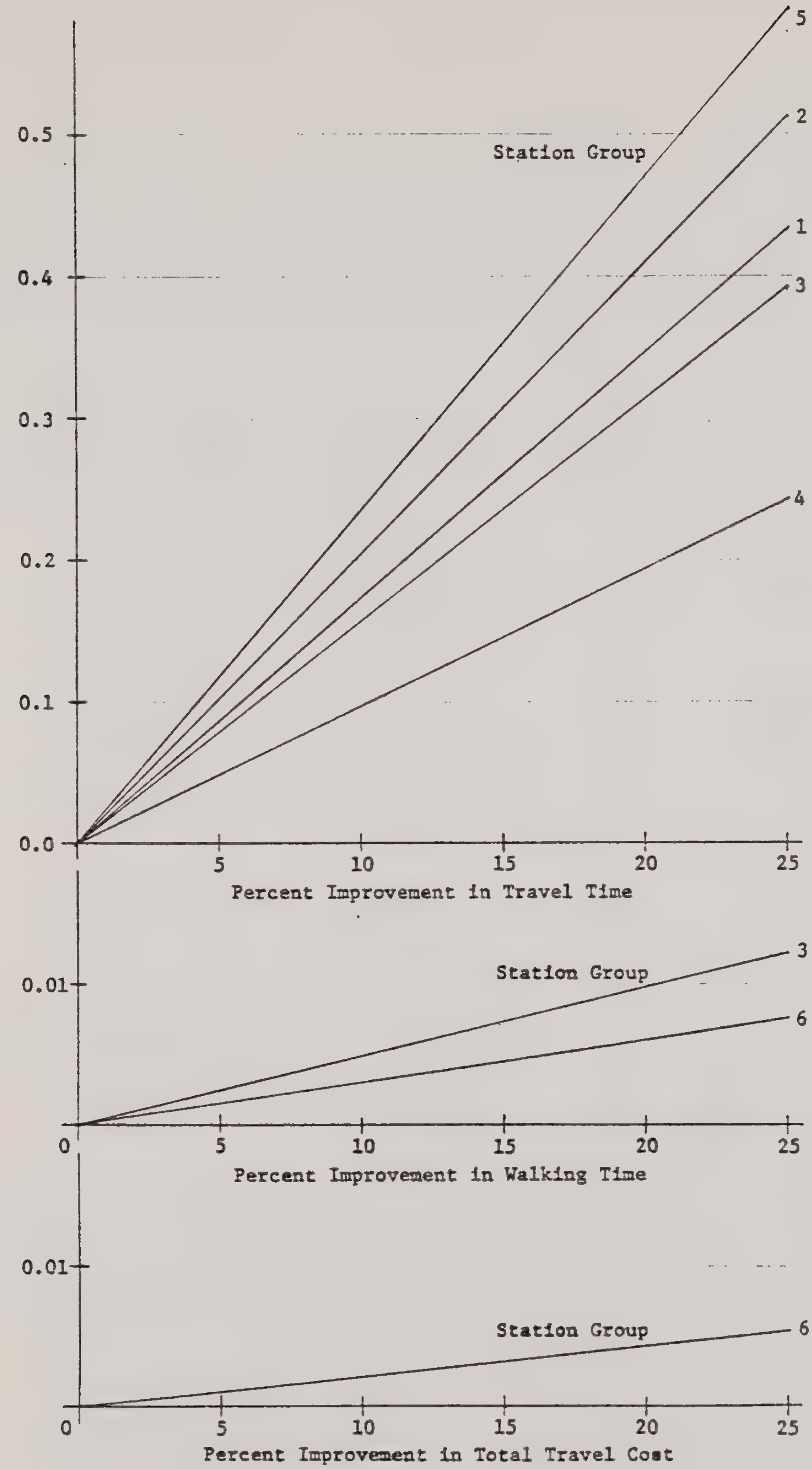


Figure 3

SENSITIVITY OF BART CHOICE PROBABILITY TO PERCENT IMPROVEMENT IN BART ATTRIBUTE VALUES

BART-AUTOMOBILE CHOICE, WORK TRIPS

Table 35

SENSITIVITY OF BART CHOICE PROBABILITY TO 25% ATTRIBUTE IMPROVEMENT
BART-AUTO CHOICE, WORK TRIPS

Attribute	Station Group[a]	Percent Attribute Improvement	Actual Attribute Improvement	Increase in BART Choice Probability	Percent Increase in BART Ridership[b]
Total time	1	25	11 minutes	0.0433	6%
	2	25	17 minutes	0.0511	15
	3	25	13 minutes	0.0392	8
	4	25	14 minutes	0.0242	4
	5	25	17 minutes	0.0589	19
	All	25	15 minutes	0.0386	5
Walking time	3	25	2 minutes	0.0120	3
	6	25	2 minutes	0.0075	1
	All	25	2 minutes	0.0036	1
Total cost	6	25	$0.45	0.0052	1
	All	25	0.38	0.0014	<1

a. Station Group 1: McArthur, 19th Street, 12th Street, Lake Merritt, Oakland West stations.
Station Group 2: North Berkeley, Berkeley, Ashby stations.
Station Group 3: Orinda, Rockridge stations.
Station Group 4: Fruitvale, Coliseum, San Leandro, Bay Fair stations.
Station Group 5: Richmond, El Cerrito del Norte, El Cerrito Plaza stations.
Station Group 6: Concord, Pleasant Hill, Walnut Creek, Lafayette stations.
Station Group 7: Fremont, Union City, South Hayward, Hayward stations.

b. Increase in BART ridership caused by diversion of trips automobile-to-BART. Diversion from bus and new trips are excluded.

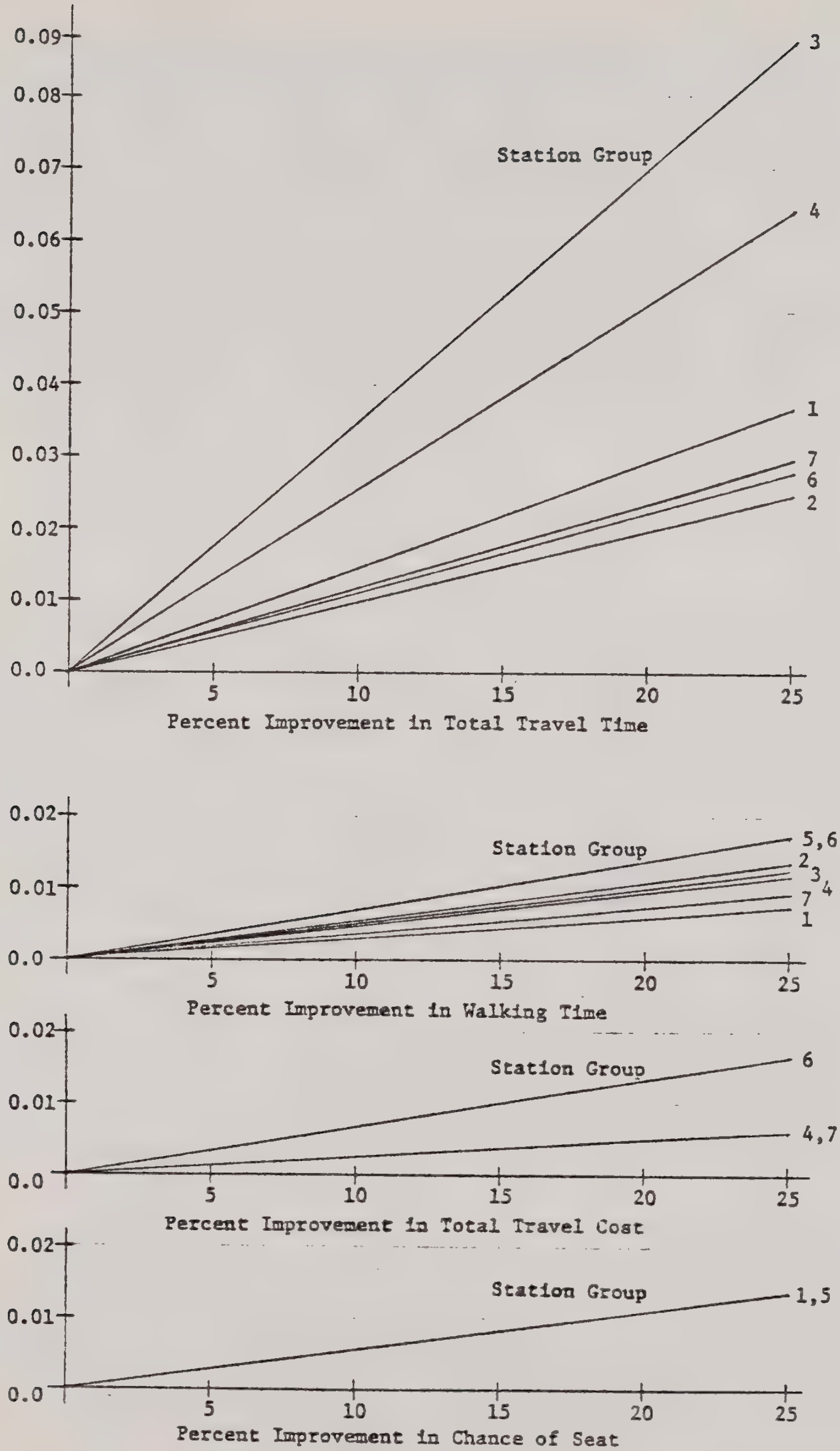


Figure 4

SENSITIVITY OF BART CHOICE PROBABILITY TO PERCENT IMPROVEMENT IN BART ATTRIBUTE VALUES

BART-BUS CHOICE, WORK TRIPS

Table 36

SENSITIVITY OF BART CHOICE PROBABILITY TO 25% ATTRIBUTE IMPROVEMENT
BART-BUS CHOICE, WORK TRIPS

Attribute	Station Group[a]	Percent Attribute Improvement	Actual Attribute Improvement	Increase in BART Choice Probability	Percent Increase in BART Ridership[b]
Total time	1	25	12 minutes	0.0365	10%
	2	25	16 minutes	0.0242	13
	3	25	13 minutes	0.0875	14
	4	25	14 minutes	0.0641	16
	6	25	16 minutes	0.269	5
	7	25	16 minutes	0.0299	4
	All	25	15 minutes	0.0397	3
Walking time	1	25	3 minutes	0.0076	2
	2	25	4 minutes	0.0137	8
	3	25	3 minutes	0.0126	2
	4	25	3 minutes	0.0118	3
	5	25	3 minutes	0.0166	15
	6	25	2 minutes	0.0168	3
	7	25	3 minutes	0.0091	1
	All	25	3 minutes	0.0138	1
Chance of seat	1	25	0.42 load factor	0.0137	4
	All	25	0.34 load factor	0.0012	<1
Total cost	4	25	$0.27	0.0059	2
	6	25	0.39	0.0162	3
	All	25	0.31	0.0065	<1

a. Station Group 1: McArthur, 19th Street, 12th Street, Lake Merritt, Oakland West stations.
Station Group 2: North Berkeley, Berkeley, Ashby stations.
Station Group 3: Orinda, Rockridge stations.
Station Group 4: Fruitvale, Coliseum, San Leandro, Bay Fair stations.
Station Group 5: Richmond, El Cerrito del Norte, El Cerrito Plaza stations.
Station Group 6: Concord, Pleasant Hill, Walnut Creek, Lafayette stations.
Station Group 7: Fremont, Union City, South Hayward, Hayward stations.

b. Increase in BART ridership caused by diversion of trips automobile-to-BART. Diversion from bus and new trips are excluded.

(equivalent to an average 15-minute reduction for people making a BART-bus choice) is estimated to give rise to an increase of 0.0397 in BART choice probability and a corresponding 3% increase in total BART ridership resulting from diversion of trips bus-to-BART.

Table 36 suggests that a 25% decrease in walking time, equivalent to a 3-minute decrease on average, would increase BART choice probability by 0.0138, corresponding to a 1% overall increase in BART ridership. A 25% improvement in seat availability would increase BART choice probability by 0.0012, corresponding to less than a 1% increase in BART ridership overall. A 25% decrease in total travel cost (representing an average fare decrease of $0.31) would increase BART choice probability by 0.0065 and BART ridership by less than 1% as a result of bus-to-BART diversion.

Conclusions

The results summarized in the previous two sections indicate that BART could potentially capture significantly greater shares of the work trip market if total BART travel times (and the associated time-related dependability attribute) were to be improved. However, very large improvements are indicated as being necessary. This is illustrated by Table 37 which gives data on actual and potential BART ridership from the 1974 transbay travel survey. The table shows that a 25% across-the-board reduction in peak-period BART trip travel times, which at an average of 15 minutes per trip represents a generous "upper bound" to feasible reductions in travel times, would result in an estimated increase of about 2,200 daily transbay work travelers, or only about an 8% increase in ridership. A 10% decrease in peak-period BART travel times, which at 6 minutes on average probably represents a more reasonable hypothetical reduction in average BART travel times, would result in an increase of about 900 daily transbay work travelers or only about a 3% increase in work-trip ridership. (Of course, these estimates assume that automobile and bus travel times, and all other BART, automobile, and bus attribute values remain unchanged.)

The above reductions in BART ridership predicted to result from reductions in BART travel times and costs appear low. As already stressed in earlier chapters, the attribute satisfaction-based mode choice models developed in this study are primarily intended as explanatory models and should be viewed suspiciously as predictive tools. The imprecise nature of the estimated Q/X relationships also contribute to error in the predictions.

Aside from general uncertainties stemming from these causes, there is reason to suspect that the simple ridership prediction procedure used in the study understates the ridership change resulting from a given change in an attribute value, say travel time. This is because, as

Table 37

ESTIMATED INCREASE IN BART RIDERSHIP RESULTING FROM 25% DECREASE IN TOTAL TRAVEL TIME
TOTAL TRANSBAY WORK TRIPS

Station Group	Mode Choice Set	Estimated Travel Population[a]	Existing BART Riders[b]	25% Decrease in Total BART Travel Time: Increase in Choice Probability	Increase in BART Ridership	Percent Increase in BART Ridership
1	BART-Auto	4,400	2,900	0.0433	190	5%
	BART-Bus	1,700	600	0.0365	60	2
	Total	6,100	3,500		250	7%
2	BART-Auto	5,200	1,800	0.0511	270	11%
	BART-Bus	3,500	600	0.0242	80	3
	Total	8,700	2,400		250	14%
3	BART-Auto	4,800	2,400	0.0392	190	5%
	BART-Bus	2,100	1,300	0.0875	180	4
	Total	6,900	3,700		370	10%
4	BART-Auto	7,300	4,400	0.0242	180	3%
	BART-Bus	3,900	1,600	0.0641	250	4
	Total	11,200	6,000		430	7%
5	BART-Auto	2,000	600	0.0589	120	15%
	BART-Bus	1,700	200	0,0242	40	5
	Total	3,700	800		160	20%
6	BART-Auto	9,100	5,000	0.0392	360	4%
	BART-Bus	7,100	4,200	0.0279	200	2
	Total	16,200	9,200		560	6%
7	BART-Auto	3,200	2,400	0.0242	80	2%
	BART-Bus	1,400	1,000	0.0298	40	1
	Total	4,600	3,400		120	3%
All	BART-Auto	36,000	19,500	0.0386	1,390	5%
	BART-Bus	21,400	9,500	0.0397	850	3
	Total	57,400	29,000		2,240	8%

a. Estimated transbay trips to West Bay zones around the BART Daly City Line stations.
b. October 1974.

Source: BART Impact Program, October 1974 Surveys of Transbay Travel.

documented in Chapter III, the satisfaction rating variables for many of the attributes correlate positively with the travel time variable. Thus, reducing overall travel time will improve travelers' satisfaction with attributes included in the model besides travel time itself. However, in the prediction procedure used here, it is implied that only satisfaction with BART travel time is increased as travel time is reduced. The influence of changes in satisfaction with the other related attributes is not taken into account. Thus, the attribute satisfaction-based mode choice models (incorporating the Q/X relationships) may well give low estimates of the sensitivity of BART ridership to some attribute changes.

Alternatively, one may use the mode choice models estimated directly from the reported attribute values to analyze the likely sensitivity of BART ridership to changes in BART travel time and cost (see Chapter VII). Table 38 compares BART ridership sensitivity estimates as derived from (1) the attribute value-based models and (2) the attribute satisfaction-based models.

Table 38 shows that much larger increases in ridership are predicted by the attribute value-based model: According to the attribute value-based model, a 25% (15-minute) average decrease in total BART travel time would give rise to a 26% increase in BART ridership (accounting for diversion from both automobile and bus). In contrast, according to the attribute satisfaction-based model the same 25% reduction in BART travel time would increase BART ridership by only 8%. Similarly, a 25% ($0.33) decrease in BART travel costs is estimated by the attribute value-based model to result in a 12% increase in BART ridership, whereas the attribute satisfaction-based model estimates only a 1% increase in ridership.

Of course, the attribute value-based model results are also subject to errors and uncertainties for many of the same reasons as apply to the attribute satisfaction-based model predictions. However, the former are not affected so seriously by the intercorrelation problems identified for the attribute satisfaction based model, and may represent a more realistic assessment of the likely results of reductions in BART travel times.

Table 38

BART RIDERSHIP CHANGES PREDICTED BY ATTRIBUTE VALUE-BASED AND ATTRIBUTE SATISFACTION-BASED MODELS

Mode Choice	Attribute	Change in Attribute Value	Change in BART Choice Probability	Percent Change in BART Ridership
Attribute Value-Based Model				
BART-Auto	Total time	15 minutes	0.1033	13%
	Total cost	$0.38	0.0380	5
BART-Bus	Total time	15 minutes	0.1835	13
	Total cost	$0.31	0.0930	7
Attribute Satisfaction-Based Model				
BART-Auto	Total time	15 minutes	0.0386	5%
	Total cost	$0.38	0.0014	<1
BART-Bus	Total time	15 minutes	0.0397	3
	Total cost	$0.31	0.0065	<1